APPLICATIONS OF NEAR-SURFACE GEOPHYSICS IN THE SEARCH FOR GRAVES IN MAORI URUPA

A project submitted in partial fulfilment
For the degree of
Bachelor of Science with Honours
In
Engineering Geology

LEAH BATEMAN

University of Canterbury
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FRONTISPIECE

(Photograph by Lee, 2003)

ABSTRACT

Maori urupa (burial grounds) are culturally significant sites that demand appropriate sensitivity and respect. Due to the loss of oral records some locations of the older graves are no longer known. Therefore, non-invasive, non-destructive, near-surface geophysical techniques have been applied at two urupa on Banks Peninsula in an attempt to delineate the position of the unmarked graves.

Prior knowledge that Maori graves are traditionally aligned facing east aided in survey design. The sites were surveyed using shallow electromagnetic (EM), magnetometer/gradiometer and ground-penetrating radar (GPR) techniques. There was some data processing carried out.

Geological factors and cultural noise (such as fences, trees and reinforced concrete) degraded the quality of some of the individual data sets. However, conducting a multi-parameter geophysical survey enabled the objectives to be achieved. It is believed that this method was successful in delineating the likely positions of the unmarked graves at Koukourarata and Wairewa. However, due to the sensitive nature of the site excavations to confirm geophysical findings are not appropriate.

There were clusters of graves identified in one area at Koukourarata. A further area of interest was highlighted as a possible locality for graves at this site. At Wairewa, anomalies were present in clear rows, indicating the probable positions of unmarked graves.

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THANK-YOU.

CHAPTER 1 : INTRODUCTION

1.1 PROJECT BACKGROUND

Maori urupa (burial grounds) are considered tapu (sacred) in Maori culture. Therefore, these culturally significant areas demand appropriate sensitivity and respect. Non-invasive, non-destructive geophysical methods were selected in an attempt to delineate the positions of previously unmarked graves in two Maori burial sites on Banks Peninsula. There are over 150 registered indigenous sites in New Zealand (Nobes, 1999) many of these do not have all graves located and marked. This problem is not unique to New Zealand, various scared indigenous sites or areas of historical interest exist around the world.

The problem of locating unmarked graves using geophysical methods is not a new phenomenon (Bevan, 1990; Nobes, 1999 & 2000). However, each site is unique and the geophysical response will be dependent on the geology of the site, nature of the burial and the effects of other cultural influences such as power lines, fences *etcetera*.

Electromagnetic (EM), magnetometer/gradiometer and ground penetrating radar techniques were utilised to determine the positions of previously unknown graves. Priori knowledge was valuable for guiding survey design, however, the significance of utilising multi-parameter surveys to constrain findings cannot be emphasised enough. There was limited processing of data sets to aid in interpretation.

1.2 AIMS AND OBJECTIVES

The initial aim of this project was to determine whether the described techniques could be utilised for the location of graves in the possibly electrically conductive loess soils of Banks Peninsula. A further objective was to examine the influence of cultural interference, that is, assess how the quality of data was affected by the presence of metal objects, fences, power lines *et cetera*.

At Koukourarata (Port Levy) the exact location and extent of the urupa was unknown. The aim was to locate and define the boundaries of the burial site to enable the local hapu to erect a fence around this culturally significant area. In contrast, Wairewa (Little River) is an active urupa, that is, still currently in use. Therefore, the extent of the site was clearly defined, however, it was not known if all the graves contained markers. The aim was to determine if occupancy of the site was greater than indicated by the headstones.

Results obtained were variable. Some clear conclusions were able to be drawn for the site at Koukourarata. However, results at Wairewa can be best described as vague due to significant cultural disturbance. Given the sensitive nature of the sites, one cannot think of a more appropriate, successful method to locate determine the position of the graves.

1.3 PROJECT FORMAT

Chapter 2 provides descriptions of the individual sites, encompassing the locations, local geology and geomorphic features. Chapter 3 outlines the geophysical techniques utilised in this investigation, briefly detailing the principles of each method and the equipment employed in the surveys. The survey design and employment of these techniques at Koukourarata and Wairewa is described in Chapter 4 along with the data processing that was undertaken. The data quality and results of the EM, magnetometer/gradiometer and GPR are presented in Chapter 6, each site and technique is addressed separately. Results are also discussed in Chapter 6, which is followed by conclusions in Chapter 7. Conclusions include the limitations of this investigation.

CHAPTER 2 – SITE DESCRIPTIONS

2.1 INTRODUCTION

Knowledge of a site gained by observations and research prior to investigation can be a valuable aid in guiding a geophysical survey. The following chapter outlines the location and background of each site. Information on the local geology and observation of the geomorphology is described along with the significance for the investigation. There is also a description of the cultural influence at the sites as these affected results.

2.2 LOCATION & BACKGROUND

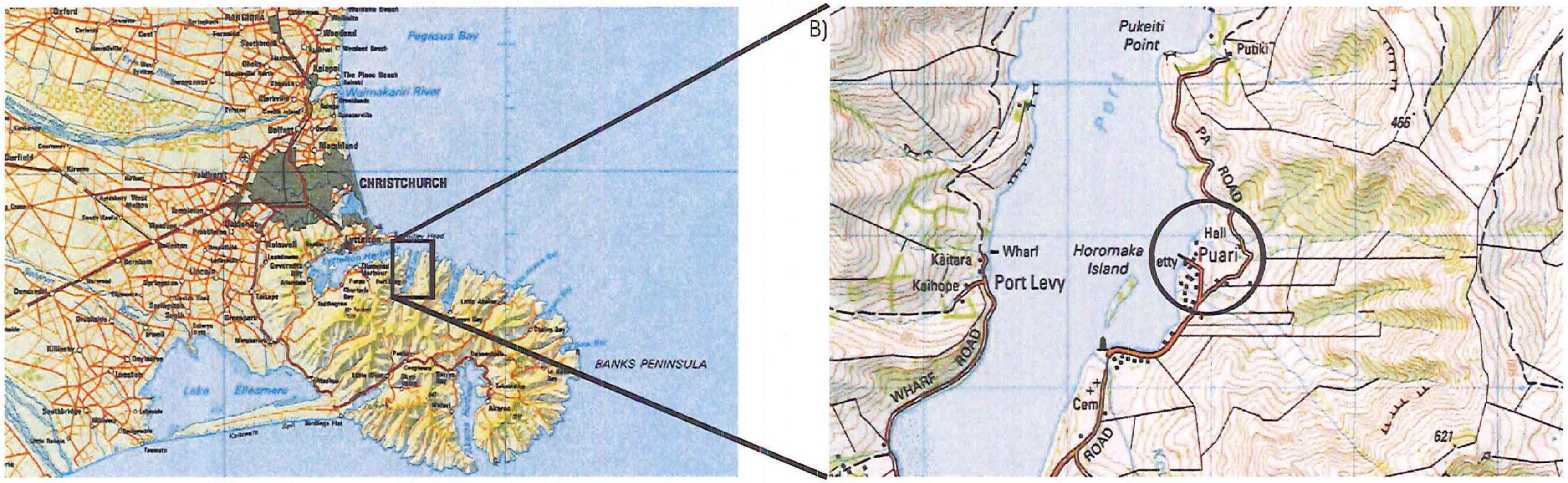
Both urupa are situated on Banks Peninsula, in North Canterbury. Koukourarata and Wairewa are of historical significance as they were important centres for Maori throughout the eighteenth and nineteenth centuries. The cultural ties to the areas are still prevalent today.

2.2.1 Koukourarata

Koukourarata is a shallow harbour situated on the northern slopes of Banks Peninsula (Fig. 2.1a). The small, predominantly Maori settlement of Puari is located on the eastern shore of the inlet (Fig. 2.1b).

The area is rich in Maori culture and history. The settlement of Puari was a thriving centre for Maori. The population suffered an attack in the 1820's when it became involved in the inter-tribal Kai Huanga feud (Jacobson, 1917), a Sicilian-style affair that involved most of Banks Peninsula Maori. Koukourarata also faced the brunt of a raid by Ngati Toa fighting chief, Te Rauparaha. The raid took place when Te Rauparaha's party was returning home to Kapiti Island after decimating the Ngai Tahu stronghold at Onawe (Taylor, 1950). Once peace had been restored, many prisoners chose to return to Puari and the area flourished.

A) B)



C)

(Photograph by Jol, 2003)

Fig. 2.1 : A) Location of Koukourarata (Port Levy Harbour)
B) The urupa is situated in the hamlet of Puari
C) Photograph of survey area at Koukourarata, taken in January, 2003. View looking south-west.

The people of Puari had a good relationship with European settlers. The port was a favourite anchorage for whalers and several settlers bought sections and began farming the region. Koukourarata was the first area to receive the Christian message (Ogilvie, 1990). The site of the South Island's first Anglican church lies adjacent to the urupa.

The urupa is no longer active, that is it is not currently used for burials. Oral tradition indicates that the burial grounds were fully occupied which led to the formation of a new urupa at the head of the harbour (Ramsden, pers. comm., 2003). The general location of the old burial grounds can be obtained from some of the original survey maps (Fig. 2.2), however, the extent of the old urupa is not fully known. The urupa is situated in what is currently a paddock used for grazing sheep and cattle.

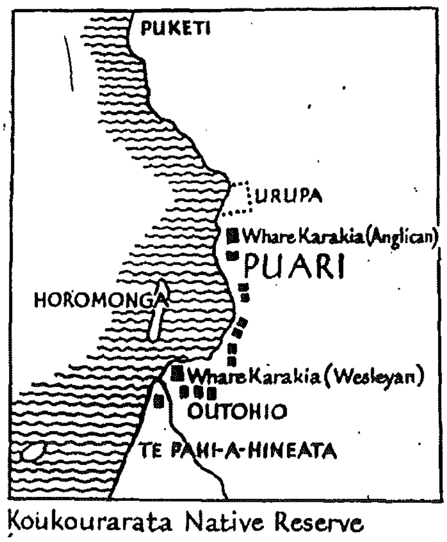


Fig. 2.2 : Survey map of Koukourarata (Carrington, 1849).

There are two distinct markers indicating graves: one is a concrete headstone; the other is enclosed by barbed wire fence. There is also an interesting arrangement of rocks that may be indicative of a grave. The known graves face east towards rising sun as is consistent with Maori tradition (Nobes, 1999).

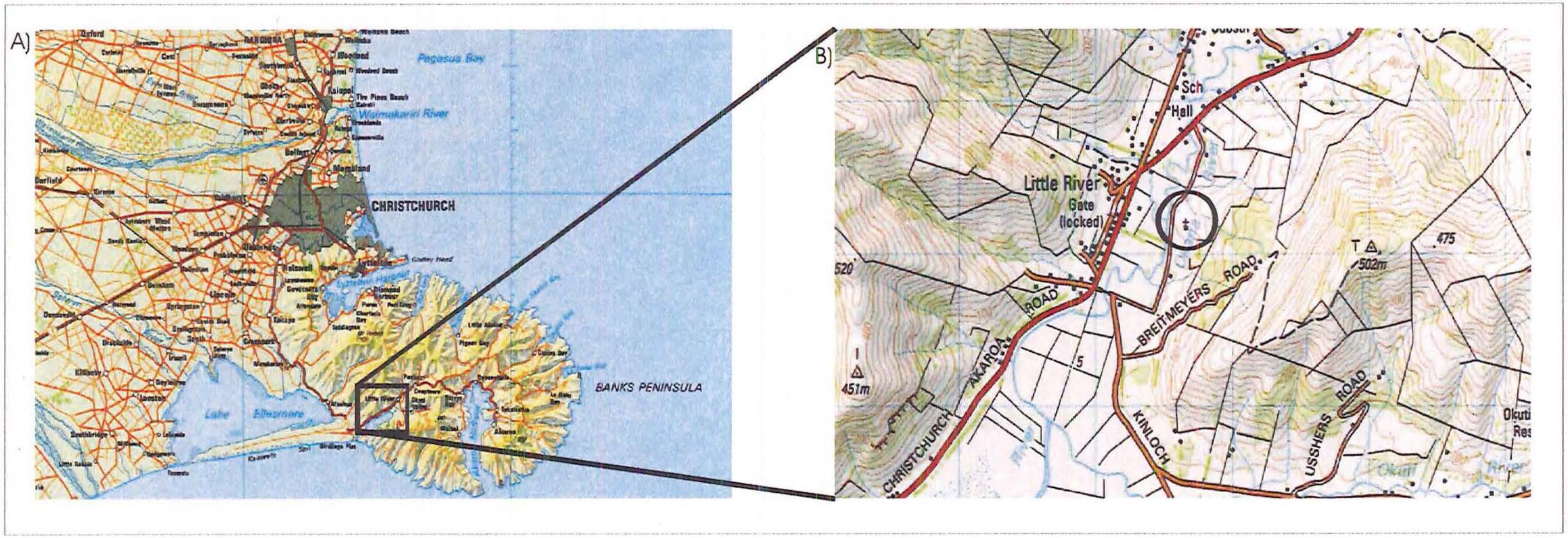
2.2.2 Wairewa

Wairewa is situated on the southern side of the Peninsula at the head of Lake Forsyth (Fig.2.3).

Wairewa was a strategic centre for Maori as it is effectively the gateway from the Canterbury Plains to the Peninsula. The Wairewa Pa was located on the banks of the Okana River and the centre was a bustling settlement. Like Koukourarata, Wairewa was involved in the Kai Huanga feuds. Residents of Wairewa composed part of the war party that marched on Taumutu and they themselves bore the brunt of more than one attack (Ogilvie, 1990). Te Rauparaha also sent scouts to Wairewa, but found that the population had fled before an attack could be planned (Taylor, 1950).

The Maori population at Wairewa was still recovering from these harsh times when the sale of the Akaroa Block purchase meant European settlement of the area began in earnest. The effects of disease, land loss and pollution of the local water supply (from the newly formed timber mills) were evident at Wairewa Pa. Typhoid fever was rife and the population were affected with other European ailments such as measles, mumps, whooping cough, venereal disease and a variety of poxes (Ogilvie, 1990). The population at Wairewa was severely affected by such disorders.

The urupa is located on a hill east of the town, facing south overlooking the lake. There are two parts to the urupa. The northern side of the site is still used for burials and contains mostly fully concrete capped graves. The southern side is the old urupa which contains 19 separate marked graves. It is thought that there are other burials within this section of the site; the total number is unknown. As at Koukourarata, the graves are orientated facing east.



(Photograph by Jol, 2003)

Fig. 2.3 : A) Location of Wairewa (Little River) township. The town can be seen at the head of Lake Forsyth.
B) The urupa is marked by a cross and is situated east of the township.
C) Photograph taken from survey January, 2003. View looking south towards Lake Forsyth.

2.3 SITE GEOMORPHOLOGY

2.3.1 Koukourarata

The area identified for the survey is located adjacent to the coast. The region is of quite steep topography. The marked graves are situated on a small platform; this is thought to be the location of the old urupa. Within this area, there are a series of mounds and dips in the earth which could be indicative of grave sites.

There are small gullies at both ends of the field. The survey was carried out between these gullies. There is a slump within the survey area; it was thought it unlikely for any burials to be in this location. The investigation was extended beyond the location of the marked graves due to the position of two Ngaio trees, as it is common in Maori culture for Ngaio trees to be planted at the corners of urupa.

2.3.2 Wairewa

The Wairewa urupa is also situated on a hill; the marked graves lie perpendicular to the slope. A row of large macrocarpa trees separate the new and old sections of the urupa. The grass is kept short and several small trough-like features can be easily seen. These could be representative of burials.

2.4 SITE GEOLOGY

The knowledge of underlying geology of a site can aid in understanding and interpretation of the geophysical results. The two sites are situated relatively close to one another and therefore have a similar geological history.

2.4.1 Basement

The Lyttleton Volcanics Group forms most of Banks Peninsula. The volcanics are built up on a high standing area of Torlesse Supergroup basement (Sewell, 1988). Hawaiian-style volcanism commenced 10-12 million years ago and resulted in a sequence of basaltic lava flows interbedded with ash and laharic material (Brown & Weeber, 1992).

The volcanic material has a typical basaltic mineralogy. It is primarily composed of plagioclase feldspar, augite, olivine, magnetite, amphibole and minor amounts of apatite (Weaver, pers. com., 2003). The mineral magnetite is high is iron and therefore strongly magnetic (Shelley, 1985). The presence of magnetite must therefore be considered when analysing results particularly from the EM and magnetometer/gradiometer. The effect of magnetite in the bedrock on the results will be dependent on the thickness of the cover material.

2.4.2 Cover Material

Banks Peninsula loess is the main cover at Koukourarata and Wairewa. Loess is fine wind-blown silt to clay material. It is derived from glacial and river erosion of the Southern Alps during the Quaternary (Brown & Weeber, 1992) and deposited on Banks Peninsula due to the prevalent north-west wind.

The thickness of the loess around the peninsula varies significantly. It mantles most of the steep slopes and can be up to 20 m thick in the gullies. The thickness of the loess cover at Koukourarata and Wairewa was not known, and due to the culturally sensitive nature of the sites, cores could not be taken to give a depth to bedrock.

Banks Peninsula loess is predominantly composed of quartz and alkali feldspar with a small component of muscovite (Weaver, pers. com., 2003). If the material is weathered, the feldspars may appear as clays (kaolinite and sericite) (Weaver, pers. com., 2003). The geophysical response to the loess soils is dependent on the clay content. Clays can be conductive due to the presence of ions in the lattice. In EM surveys, other features may be masked by conductive soils. Clays can also be problematic for radar investigations; if the ground is moderately to highly conductive the GPR signal will be severely attenuated (Theimer et al., 1994; Nobes, 2000).

2.5 CULTURAL INFLUENCES

The amount of cultural disruption on a site can affect the geophysical results. Objects such as fences, power lines, graves, *et cetera*, may all yield geophysical anomalies. Ground disturbance of any kind may also affect the result.

2.5.1 Koukourarata

There are some minor cultural features that may interfere with geophysical results at the Koukourarata site.

Electrically conductive barbed wire surrounds one of the graves and the edge of the field. Like the fence, the power lines that cross the survey grid are also conductive. In New Zealand power lines operate at a frequency of 50 Hz therefore, harmonics of 50 Hz may be evident in surveys, such as the EM survey. Therefore, it is not advisable to run geophysical equipment at this frequency in this area, even so presence of power lines could potentially affect results.

The ground has been fallowed for agricultural purposes. It is likely the top 0.50 m of the cover has been disturbed. This may result in pockets of air or moisture that may yield an anomalous response. A response from the concrete headstone can also be expected.

2.5.2 Wairewa

The Wairewa site is still used for burials. Therefore, there are many cultural influences that can be seen in the results. Wire fences around the perimeter of the site are electrically conductive.

Several of the graves are marked with iron fences or wire, other concrete graves may have reinforcing in them. Many of the marked graves could be clearly seen in the results possibly masking other likely burials.

There was a large response from the trees. This is likely to be due to the differential moisture content surrounding the trees. The site was cleared of gorse and scrub. Some of the larger trees had also been removed prior to surveying resulting in ground disturbance.

2.6 SUMMARY OF POSSIBLE NON – GRAVE INFLUENCES

The cultural and geological influences that are possibly present at each site surveyed are summarised in table 2.1.

Table 2.1 : The possible non-grave survey influences.

Location	Possible causes of 'noise'
Koukourarata	- Conductive bedrock high - Influence of fences - Presence of power lines - Ground disturbance from agriculture
Wairewa	- Influences from fences - Presence of headstones and iron fences marking graves - Existence of large trees - Disturbance from removal of trees and clearing of the site

CHAPTER 3 : GEOPHYSICAL TECHNIQUES

3.1 INTRODUCTION

All geophysical methods measure changes in the Earth's subsurface properties. Methods can be passive, that is utilize the gravitational, magnetic, electrical and electromagnetic fields of the Earth to seek local anomalies, which may be indicative of the target (Kearey & Brooks, 1984). Techniques can also be active, involving the generation of an energy source.

The response of the earth to these techniques is a function of the subsurface physical properties (Kearey & Brooks, 1984). Properties can include, density, acoustic and shear velocity, thermal and electrical conductivity, resistivity, magnetic susceptibility and dielectric permittivity.

This chapter concentrates on the three geophysical techniques employed in the investigation. The basic principles of each method and the required equipment are discussed for EM, magnetometer/gradiometer and GPR surveys.

3.2 ELECTROMAGNETISM

The EM method is referred to as an induction technique, as it makes use of an induced current. The method involves the propagation of electromagnetic fields in and over the earth (Telford *et al.*, 1990). If the signal is being transmitted and received on a single frequency the system is said to be operating in the frequency domain (FDEM or FEM). Time domain EM (TDEM or TEM) involves a sharp pulse of EM energy, the response decay is measured with time.

3.2.1 Basic Principles

The system employed for this investigation was a frequency domain, horizontal loop (HLEM) system. That is, the transmitter and receiver are a coplanar pair of wire loops or coils. Current is passed through the wire which generates a primary EM field. The field travels from the transmitter to the receiver by paths above and below the ground (Kearey and Brooks, 1984). If the field encounters a conductive body, eddy currents are induced to flow. This in turn generates a secondary EM field which is superimposed on the primary signal. The combination of the two fields results in a response at the receiver. Figure 3.1 demonstrates this process.

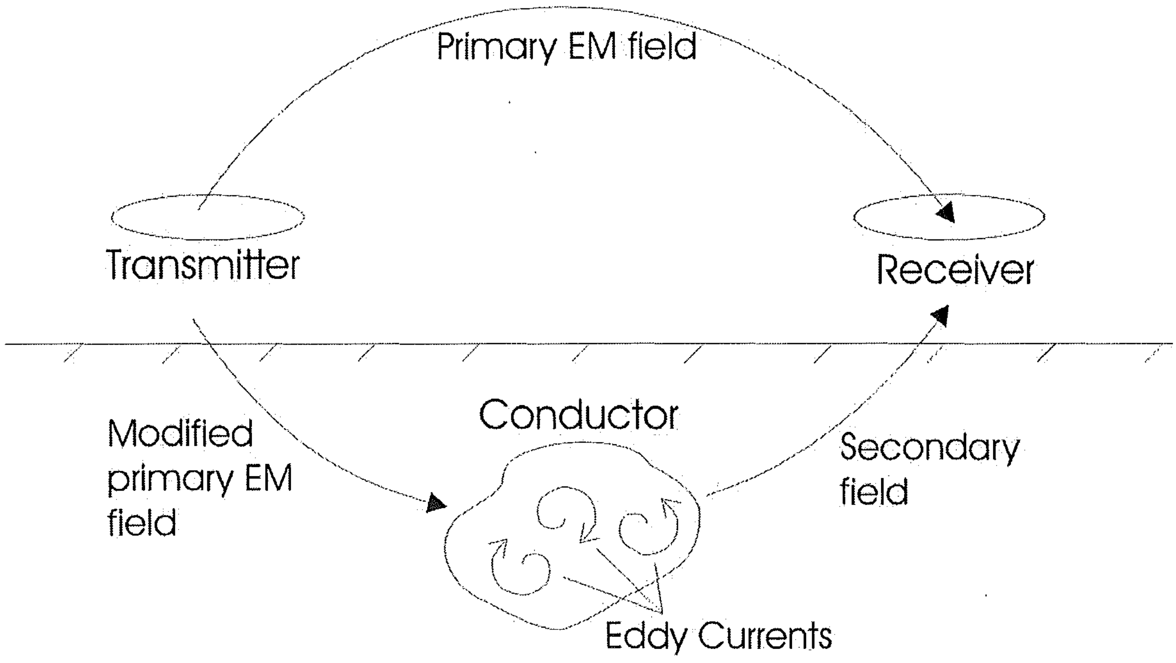


Fig. 3.1 : The basic principals of electromagnetic induction (Adapted from Kearey and brooks, 1984).

The secondary response is similar to that transmitted except it is shifted and distorted (Nobes, pers. comm., 2003). The primary field can be cancelled out and the difference in the fields, reveal characteristics about the conductor such as its location, geometry and conductivity (Kearey and Brooks, 1984).

The secondary response can be broken down into two parts. The real part is aligned with the transmitted signal, and therefore is termed the 'in-phase' component. This is measured in parts per thousand (ppt). The out-of-phase part is referred to as the 'imaginary' or 'quadrature' component. At low conductivities, which are commonly encountered in nature, the quadrature component varies linearly with conductivity, and the quadrature reading can be expressed in units of conductivity such as millisiemens per metre (mS/m).

The response is dependant on the response parameter (α) (Frischknecht, 1991)).

(3.2) $\alpha = \omega \mu \sigma l^2$

Where $\omega = 2\pi f$, μ is the free space magnetic permeability, σ = electrical conductivity and l is the length between the transmitter and receiver coils. If the ground is not at all conductive the response parameter will be zero. As conductivity rises both quadrature and in-phase response increase (Fig. 3.2). The quadrature response reaches a maximum when $\alpha = 1$. The in-phase response continues to increase rapidly until it reaches the inductive limit.

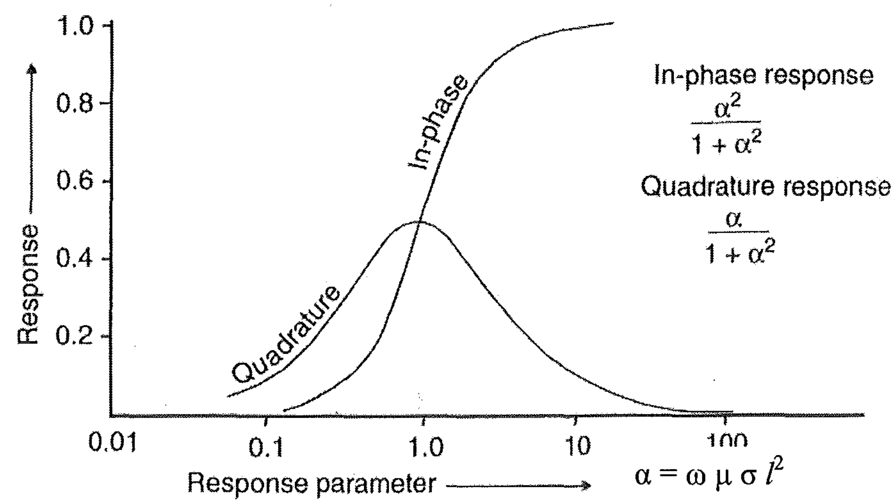


Fig. 3.2 : Response of horizontal loop EM system as a function of the response parameter (α) (adapted from Milsom, 2003).

3.2.2 Depth of Penetration

For low induction numbers the depth of penetration is dependent on the distance between the transmitter and receiver coils. EM energy decays exponentially with depth. The skin depth is the depth at which the signal strength is 37% of the strength at the surface. When the coil separation is much less than the skin depth, the depth of penetration is 1.5 times the distance between the transmitter and receiver (McNeill, 1990). This is assumed to be the case in most small scale EM surveys.

3.2.3 Equipment

A Geonics EM31™ instrument (Fig. 3.3) was employed in the survey of the sites. The instrument is a coplanar loop instrument that operates in the frequency domain. The EM31 has a 3.66 m long boom with a transmitter coil at one end and a receiver coil at the other and operates at a frequency of 9.8 Hz. There is a console in the middle of the instrument, which can be attached to the polycorder which collects the data. The polycorder is plugged into a laptop to download the data for processing and analysis.

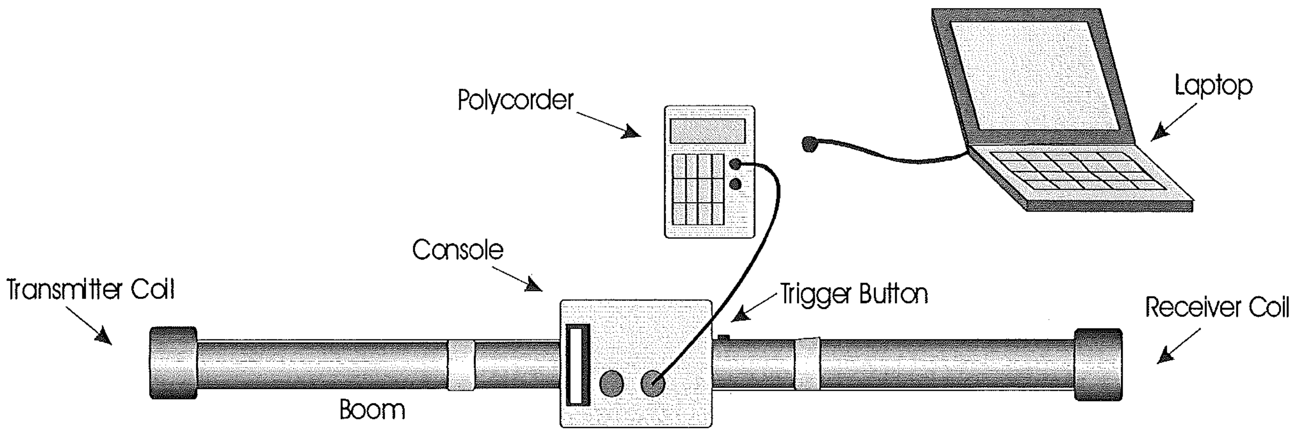


Fig. 3.3 : Geonics EM31™ instrument with polycorder to log data and laptop for data downloading

The instrument can be operated in the horizontal coplanar or vertical coplanar orientation. Having the instrument vertically approximately halves the depth of penetration. The depth to the target was unknown for this investigation, therefore the horizontal orientation was selected in which to carry out the surveys. The depth of penetration is ~ 5.5 m ($3.66 \times 1.5 = 5.49$).

3.3 MAGNETOMETER/GRADIOMETER

Magnetometers passively measure lateral changes in the Earth's magnetic field caused by subsurface variations. There are several types of magnetometer available; in this survey a proton precession magnetometer/gradiometer was employed.

3.3.1 Magnetic Fields

Magnetic fields are vector fields, that is they have a magnitude and a direction. Therefore, every point in the magnetic field can be characterised by three parameters; magnitude, declination and inclination (Kearey & Brooks, 1984). In this survey only the total magnetic field was recorded.

The degree to which a body placed in a field is magnetised, is termed the magnetic susceptibility (k) (Telford *et al*, 1990).

3.3.2 Basic Principles

There are several types of magnetometer. In this investigation, a proton precession magnetometer/gradiometer was employed. A proton precession magnetometer consists of a sensor containing hydrogen-rich fluid. The protons are aligned in the direction of the earth's magnetic field (B) (Kearey & Brooks, 1984). The fluid is surrounded by a coil of wire, when current flows in a coil it generates a magnetic field. This induces the protons to realign in the direction of the new magnetic field (Kearey & Brooks, 1984). The current is switched off and the polarizing field is removed. The force present due to the local magnetic field causes the nuclei to precess, like a spinning-top (Fig. 3.4), as they attempt to return to the original alignment. The frequency is measured by counting the precession cycles (Telford *et al*, 1990). Frequency is directly related to the magnetic field strength by (Kearey & Brooks, 1984) :

$$(3.4) \quad f = \frac{\gamma \times B}{2\pi}$$

Where γ is the gyromagnetic ratio of a proton, a known constant. A proton precession magnetometer can only measure the total magnetic field rather the magnitude of individual components. The total magnetic field in usually measured in units of nanoteslas (nT).

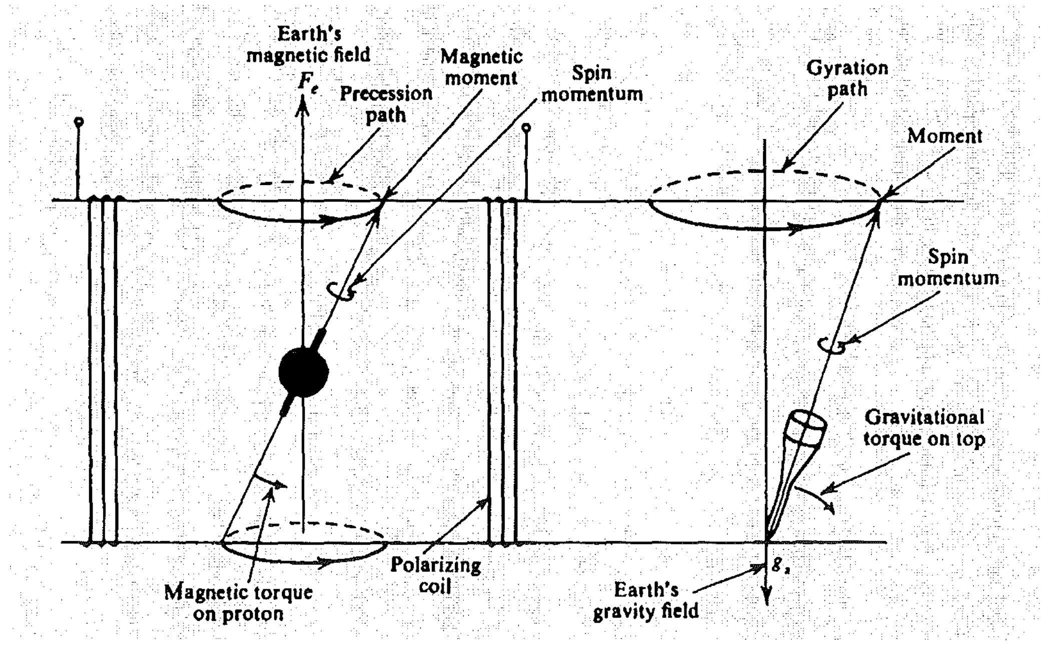


Fig. 3.4 : Spinning-top analogy applied to proton precession (Telford et al, 1990).

A gradiometer is useful as it allows for the calculation of the change in the magnetic field over a certain distance in a particular direction. For example, two total field magnetometers at different heights can be combined to obtain the vertical gradient of the magnetic field, which is more sensitive to near-surface features (Reynolds, 1997). The gradient is recorded in nanoteslas per metre (nT/m).

3.3.3 Equipment

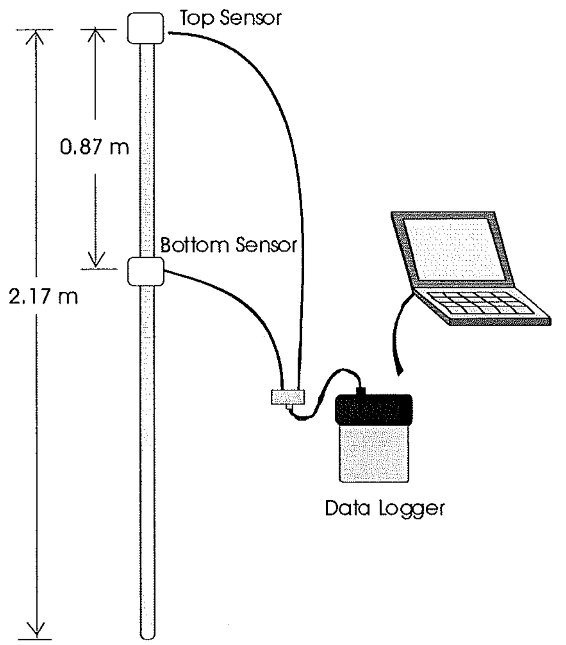


Fig. 3.5 : Geometrics G-856^{TM} proton precession magnetometer/gradiometer.

The digital magnetometer/gradiometer used was a Geometrics G-856^{TM}. The instrument is composed of two sensors on a vertical staff (Fig. 3.5). Each sensor contains high-purity decane and a coil of wire and reads the total magnetic field at that height. This allows the calculation of the vertical gradient. For accuracy the staff must be levelled before taking a reading at each station.

The readings are displayed on a data-logger which is harnessed to the operator. The logger only stores 1000 readings and therefore regular downloading to a personal computer is required.

3.4 GROUND-PENETRATING RADAR

GPR is a relatively new technique in geophysical surveying, however applications are expanding and the use of radar has grown significantly in the last decade (Davis & Annan, 1989). Radar is a wave propagation technique that utilises the response of the ground to electromagnetic energy.

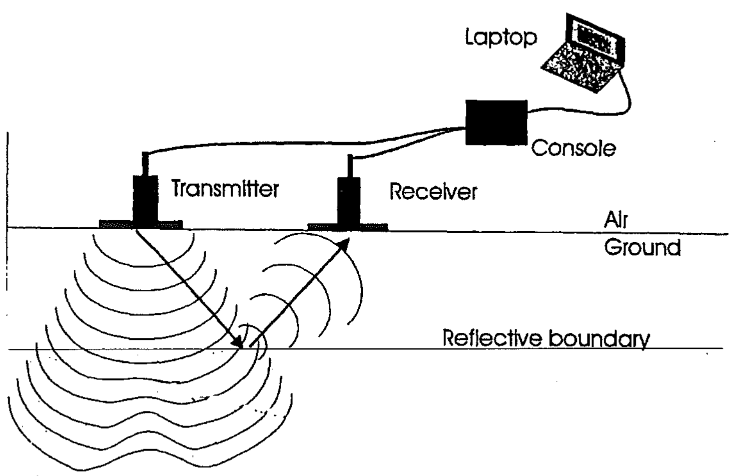


Fig. 3.6 : The basic concept of GPR. The signal is emitted from the transmitter, then is reflected and refracted at subsurface boundaries, the returning echo is detected by the receiver. This is then translated by a console and downloaded onto a laptop (Nobes, 2002).

3.4.1 Basic Principles

A short pulse of high-frequency electromagnetic energy is transmitted into the ground in the form of a wavelet that radiates downwards (Fig. 3.6) (Davis & Annan, 1989; Smith & Jol, 1995).

The velocity of a radar signal through the ground is affected by the dielectric permittivity (ε) and the magnetic permeability (μ) (Fig. 3.7). The dielectric permittivity is a measure of the ability of a medium to be polarised by an EM field (Davis & Annan, 1989).

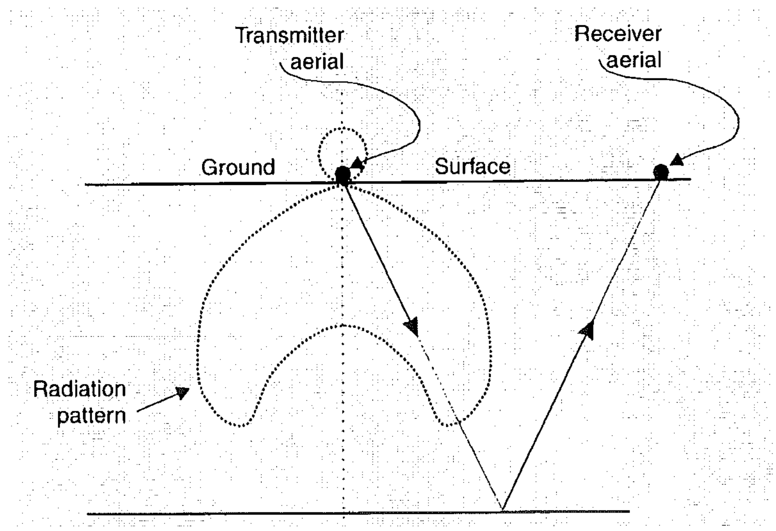


Fig. 3.7 : Radiation pattern transmitted from a GPR unit. The lobate shape will vary depending on the properties of the subsurface (Milsom, 2003).

Water has a high dielectric permittivity and therefore slows the propagation of the radar wave significantly. Fresh water has a dielectric permittivity of 80 compared with air in which $\varepsilon = 1$, the velocity of radar waves through these mediums are 0.30 m/ns and 0.033 m/ns respectively (Milsom, 2003). Therefore, the air wave arrival is the first seen on a GPR profile. The GPR system is very sensitive to changes in subsurface moisture content and only a few percent change will generate a reflection (Theimer *et al*, 1994).

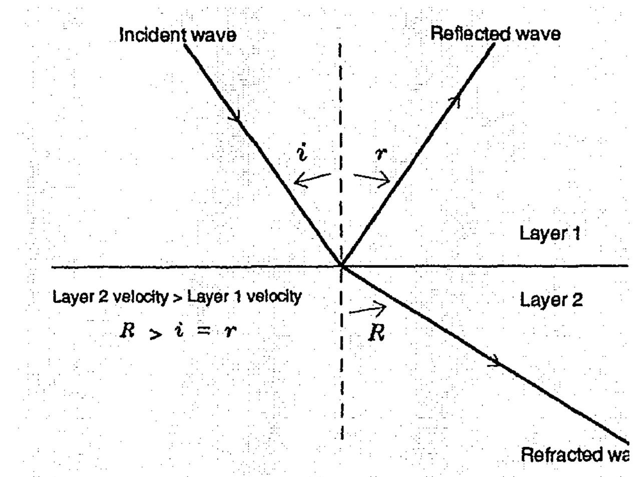


Fig. 3.8 : Reflection and refraction according to Snell's Law, at a boundary increasing in velocity (Nobes, 2003).

At subsurface boundaries, where there is a change in electrical or dielectric properties, the wavelet is refracted or reflected. The response of the wave to the boundary is governed by Snell's Law (Sheriff, 1991) (Fig. 3.8):

(3.5) $V / \sin \theta =$ constant

Simply, the when a wave touches a boundary the ratio of the velocity (V) to the sine of the angle (θ) is a constant. The receiving antenna measures the GPR 'echo' returned from subsurface boundaries (Fig. 3.10) (Nobes, 2002). This is translated through a console and then stored in a laptop. The data can be viewed on the laptop screen in real time during collection

Discrete features in the subsurface, such as a grave, can yield diffraction patterns in a radar profile (Fig. 3.9), these are primarily caused by the scattering of energy. The radar velocity affects the shape of the diffractions, with slower velocities resulting in steep diffractions

(Nobes, 2002). It is therefore important to conduct a survey in consistent weather conditions so that rain or moisture from dew on the ground surface does not affect results.

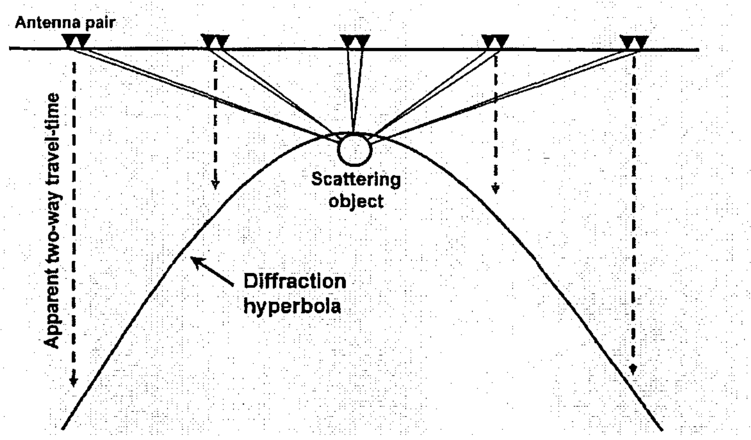


Fig. 3.9 : A diffraction hyperbola in a radar profile, created due to the presence of a discrete object in the subsurface (Nobes, 2002).

3.4.2 Resolution

Resolution and depth of penetration of a radar signal is governed by its frequency (f), velocity (V) and the wavelength (λ). These parameters are closely related. For example, at the surface, the lateral resolution (ΔR), that is the ability to distinguish between two adjacent objects, is defined by :

(3.6) $\Delta R = \lambda / 4 = V / 4f$

Therefore, only two parameters are required to calculate the third. Resolution degrades with increasing depth. A larger portion of the signal is lost due to scattering. Attenuation is a reduction in amplitude of the propagating wave with depth (Davis & Annan, 1989). Attenuation is dependent on the conductivity of a material (Theimer et al, 1994); signal strength will not decrease as rapidly within a resistive medium.

Higher frequency signals yield better lateral resolution, however result in a shallower penetration (Nobes, 1999). Therefore, selection of a frequency is a trade-off between depth and resolution.

3.4.3 Equipment

GPR systems generally consist of transmitter and receiver units, linked by fibre-optic cables to a control and recorder unit, usually a laptop PC (Milsom, 2003). In this investigation pulseEKKO 100™ and a pulseEKKO 1000™ digital GPR systems were operated at varying frequencies.

The pulseEKKO100 system consisted of two, 200MHz frequency antenna, attached to a toboggan. The power source was carried on the sled which was guided by one operator. The second operator followed carrying the laptop. The system ran on continuous mode and was primarily used as a comparison of frequencies.

Fig. 3.10 : One of the GPR systems employed in this investigation. The antennas are attached to an odometer for accuracy and ease of use. There are two operators; one directs the buggy while the other operates the laptop. (Photograph by Jol, 2003)

The pulseEKKO 1000 system, employed ran on the same principles. The transmiting and recieveing antenna were connected and attached to an odometer wheel (Fig. 3.10) to allow readings to be recorded at set intervals. Most of the investigation was carried out with 225 MHz frequency antenna, however, the antennas were interchangeable to 450 MHz frequency and provided a good example of the affects of frequency change. Operator one directed the mobile unit. The second operator carried a backpack containing the power source (a 32 volt battery) and operated the laptop viewing the radar profile in real-time.

CHAPTER 4 – DATA COLLECTION AND PROCESSING

4.1 INTRODUCTION

Three geophysical techniques were used at the Koukourarata and Wairewa sites: electromagnetics (EM), magnetometer/gradiometer and ground-penetrating (GPR), as described in chapter 3. The layout of the survey design for the individual sites is discussed in the following chapter. The survey design and data collection followed similar principles for each site. Data collection was carried out in a structured and methodical manner.

It is considered important not to lose site of the results presented by the raw data. Therefore, only limited data processing was undertaken with the aim of enhancing anomalies already present in the raw results.

4.2 KOUKOURARATA

4.2.1 EM

The usual procedure of first conducting a reconnaissance EM survey was followed (Theimer *et. al.*). Collecting EM data is relatively rapid and simple. Some raw results can be interpreted with the limited data processing that may be undertaken in the field. Therefore, it was thought to be the best approach to survey almost the entire site even if it was not a likely location for a grave, in order to narrow down the survey areas for the subsequent techniques. This would also provide a good indication of background conductivity related to the loess soils and volcanic bedrock. The EM survey was completed within 3 days.

4.2.1.1 Survey Design

The orientation of the marked graves are east–west, consistent with Maori tradition. It was assumed any other graves present would be oriented the same way. Therefore, survey lines were designed to cross perpendicular to the marked graves i.e. in a north–south direction, in order to get the maximum response. It was estimated that a grave is, on average, 2 m in length. Line spacing was set at 1 m intervals so as not to miss the target. In total 39 lines were surveyed, each approximately 95 m in length.

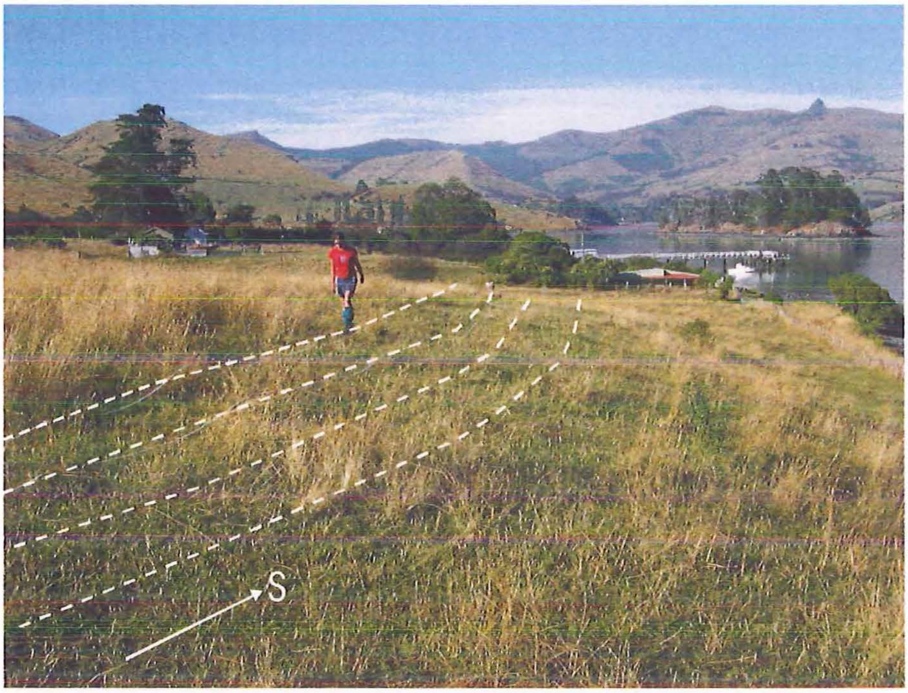


Fig. 4.1 : Survey lines at Koukourarata were orientated north – south and were spaced at 1 m intervals. The lines ran parallel with the slope. (Photograph by Jol, 2003)

The survey grid was laid out using a compass, optical square and measuring tapes. Conveniently, survey lines ran north–south, parallel with the slope (Fig. 4.1). The EM31 was operated by manual trigger and station spacing was set every 0.5 m.

4.2.1.2 Data Collection

The EM was oriented in horizontal co-planar fashion as described in chapter 3. Therefore, the depth of penetration was approximately 5.5 m with the maximum response from 1 m below ground surface. The decision was made not to proceed with a survey in vertical coplanar orientation as the maximum response would be from the surface, and would not provide any additional information about the location any graves. Both quadrature and in-phase readings were collected.

Where there were pauses in the survey, the last line was repeated. This allowed corrections of any shift in conductivity readings, as shifts can occur due to changes in temperature of the EM31 as it warms with use.

4.2.1.3 Data Processing

As mentioned above, the EM requires very little data processing in order to view the raw results. The polycorder has a limited memory; therefore, there were pauses in the survey to download the data from the EM31 to the DAT31 program on a laptop PC.

All the data were installed on the laptop. The files were then converted from raw R31 to formatted text G31 format so they could be readily understood by Microsoft Windows^{TM}, and imported to Microsoft Excel^{TM}. The repeated lines were then plotted against each other to check for data consistency the correlation was found to be good (Fig. 4.2).

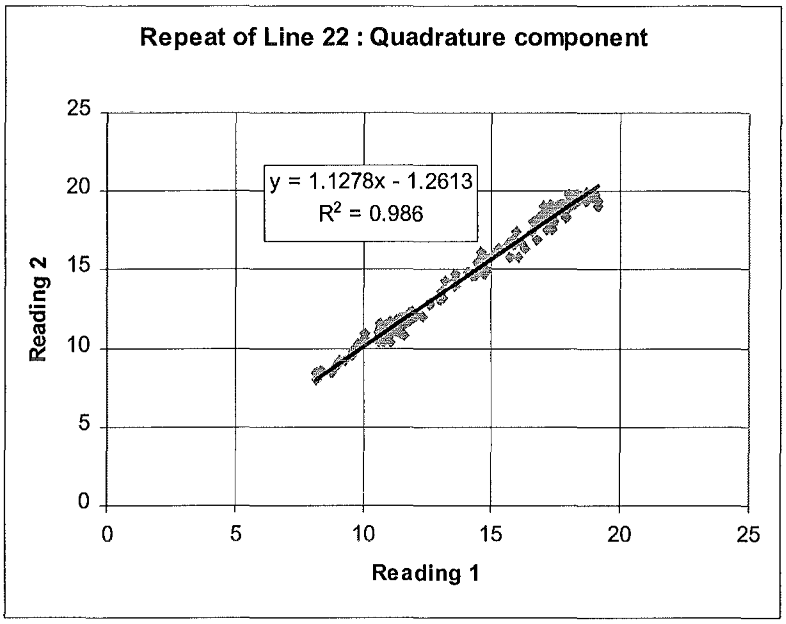


Fig. 4.2 : The regression analysis shows a 98.6% correlation between the two set of readings taken from line 22.

The median value for each line was then calculated and subtracted from the actual reading along that line, this was to ensure there were no changes in base level occurred throughout the survey. This method corrected variations in north-south trending topography. The survey lines ran parallel with the slope therefore it was not viewed necessary to correct for variations in topographic changes trending east-west.

Line numbers and positions were assigned to readings and the data was then transferred to Surfer™, allowing the conductivity to be viewed as contoured maps. The raw data showed an obvious background trend that would have masked the response from any smaller anomalies, such as a grave. The dominant background response is attributed to a suspected bedrock high. This was determined as, despite the attempts the remove topographic influences, the conductivity plot followed topography relatively uniformly. Therefore, the thickness of the moderately resistive loess soils must be much less on the hill in comparison to the depth to the bedrock further down slope. Therefore, the conductivity readings were heavily influenced by geological factors. There was also an obvious response from the slump.

There were attempts made to remove the background trend (App. I). A polynomial regression was used to define the large-scale trend (Golden Software, 1999). This was then subtracted from the raw contour map to give a residual map with the background trend removed. This was moderately successful; the background trend was still evident, but some areas appeared more textured and were located as areas of interest.

Attempts were made to highlight anomalies on the contour maps, by manually adjusting the colour gradation. There were a number of colour schemes tested; the most appropriate are used in displaying the results. The careful use of colour is important for attaining the maximum results from geophysical information.

4.2.2 MAGNETOMETER/GRADIOMETER

4.2.2.1 Survey Design

The magnetometer/gradiometer survey was conducted over the majority of the area in an attempt to reinforce the findings of the EM survey. The line and station spacings were kept consistent with the EM. The landslide area was not surveyed as it was felt the level of disturbance would affect results; this is also an unlikely location for a grave.

A base station was selected at a point within the survey perimeters that was felt to be representative of the area as a whole. Regular base station readings allowed diurnal changes in the Earth's magnetic field to be monitored and enabled correction of data.

4.2.2.2 Data Collection

The magnetometer/gradiometer survey was delayed for several days due to an unsettled geomagnetic field caused by magnetic storms in the Earth's ionosphere. The survey commenced on 5th December, 2002 and took two days to complete.

A magnetometer survey is more tedious than an EM survey to conduct and therefore, due to time constraints, the investigation area was restricted to only include survey lines 39 – 15. This was not seen as a problem as the lower lines were situated on relatively low ground (away from the marked graves), when urupa are traditionally located on a hill.

4.2.2.3 Data Processing

The magnetometer/gradiometer data logger only holds 1000 readings. Therefore, the survey had to be halted for downloading data approximately every four lines. Data were then imported into Microsoft Excel™ for easy manipulation. Line numbers and positions were assigned to the values.

The gradient was calculated for each position. The vertical gradient is equal to the difference in readings for the top and bottom sensor divided by the sensor separation (Fig 3.5). Gradiometers are often employed in small-scale surveys such as this for better resolution of shallow features (Reynolds, 1997).

The elapsed time from the start of the survey to the point at which a reading was taken was calculated from the stored times in the data logger. The based station readings were plotted against the elapsed time (Fig. 4.3). This enabled corrections for diurnal drift to be made.

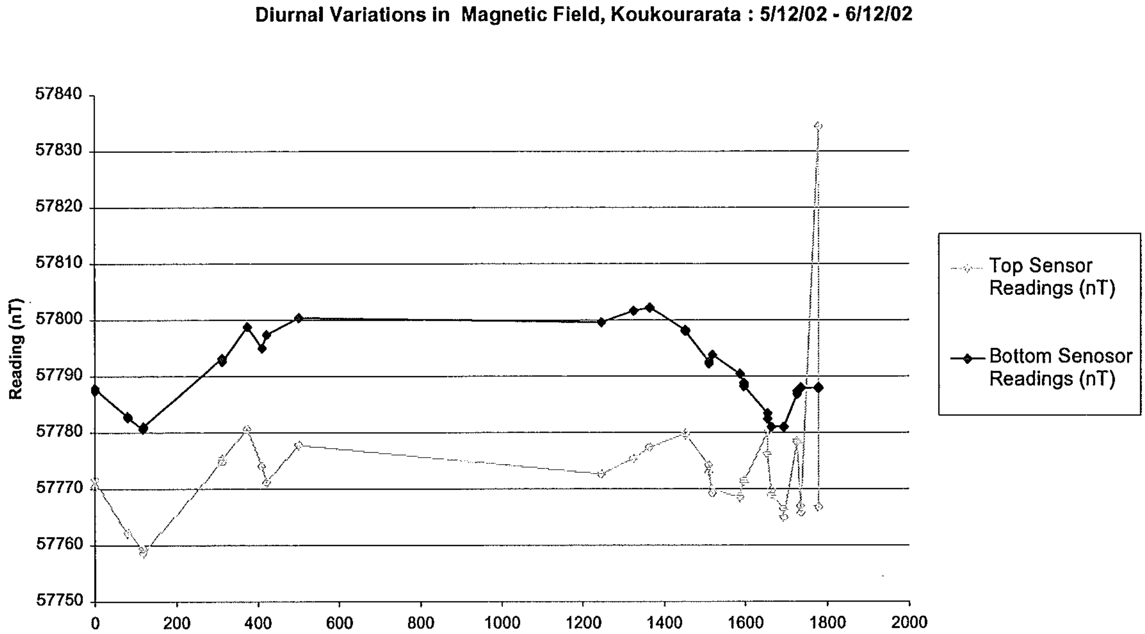


Fig. 4.3 : Graph showing the diurnal variations that occurred throughout the magnetometer/gradiometer survey at Koukourarata.

The random spike from the top sensor towards the end of the survey was removed. The survey area was small; therefore, data did not require correcting for latitude or topography.

As with the EM, the magnetic data were transferred to Surfer™ format for qualitative analysis (App. II). There were some random anomalous spikes in the data, all occurring in line 24. These spikes were not consistent with any other findings and were removed from the final data set. It is thought a sensor cable may have been worked loose during the survey and had gone some time unnoticed. The data were then contoured and a blanking file was applied in areas where contour extrapolation was unsupported.

4.2.3 GPR

The EM and magnetometer surveys highlighted two areas of interest. Therefore, it was decided follow up by surveying these two areas in greater detail with the GPR. The areas were separated into an upper grid, which contained the marked graves, and a lower grid by the shore that showed some interesting anomalies from surveys using the other techniques.

Due to weather the surveying was delayed for 1 day, however this allowed time to set out the grids in advance.

4.2.3.1 Survey Design

The upper grid consisted of 62 lines trending north–south, at 0.5 m line spacing. The survey area was extended 20 m to the north of the previous surveys to the edge of the planar; because there were some interesting anomalies on the edge of the preliminary EM and magnetometer results. Station spacing was set to 0.05 m. The upper grid was surveyed with the 225 MHz frequency pulseEKKO 1000 GPR.

The lower grid consisted of 42 lines at 0.5 m spacing, grid lines were each 35 m long and ran in the same orientation as the previous survey. The station spacing was set to 0.05 m. The area was of greater uncertainty as it was located at some distance from the marked graves. It was also on flat lying ground close to the shore, therefore it was decided that the GPR should be run at two frequencies. The pulseEKKO 100 system operated on 200 MHz frequency and was run on continuous mode. The area was also surveyed with the 225 MHz frequency GPR.

To provide a good basis of comparison between the two frequencies it was decided to proceed with a survey of a long line. The line was approximately 120 m long and was situated above the landslide, in an area that was felt to be representative of the site as a whole. As it was run on continuous mode the 200 MHz frequency line required rubberbanding. That is, the traces were placed in the correct positions in relation to ground measurements. Regularly spaced intervals were spaced out with flags, these were marked on the radar profiles. The known points were used to interpolate and position the traces correctly in space.

4.3.2.2 Data Collection

Data collection required two operators, one to pull the toboggan or buggy and the other to operate the laptop. GPR profiles can be viewed in real time on the laptop; therefore, it is easy to see when equipment (or operators) is not functioning correctly.

4.2.3.3 Data Processing

There was no CMP survey carried out at Koukourarata as the loess material was assumed to be very similar to that found in Wairewa. Therefore, the velocities obtained in the Wairewa survey were also applied to results from Koukourarata.

The two survey grids were situated in relatively planar areas, therefore no corrections for topography were required. Migrations were not applied as they have a tendency to collapse diffractions that could occur as a result of graves, thus making the targets more difficult to define.

Therefore, there was limited data processing required for the GPR results. As the radar signal is recorded, progressive saturation of the radar antennas can occur. In this situation a longer period, low frequency 'WOW' is superimposed on the returning signal (Nobes, 1999). A 'DEWOW' filter was applied to remove this occurrence.

The 200 MHz frequency GPR survey was run on continuous mode. Therefore, all the profiles required rubber-banding.

4.3 WAIREWA

The data collection and processing carried out at Wairewa was the same in principle to that at Koukourarata. However, every site is unique, so there are variations in collection and processing, which will be discussed in the following section.

4.3.1 EM

As at Koukourarata, a reconnaissance EM survey was carried out over a large proportion of the site.

4.3.1.1 Survey Design

The marked graves are oriented facing eastwards. Therefore, as at Koukourarata, the survey lines crossed the graves, once again parallel to the slope. The line and station spacings were kept consistent at 1 m and 0.5 m, respectively.

The entire cemetery, except the plot of recent concrete capped graves, was surveyed with the EM. There were 120 lines in total to be surveyed, approximately 65 m in length. The survey was completed in 3 days. Unfortunately, due to problems with the equipment, only 114 lines could be completed.

Fig. 4.4 : The survey design at Wairewa was very similar to that at Koukourarata. Survey lines ran north-south and were spaced at 1 m intervals. (Photograph by Nobes, 2003)

4.3.1.2 Data Collection

The data collection was the same as at Koukourarata (Fig. 4.4). The EM31 was orientated as a horizontal, coplanar instrument so the maximum response was from 1 m depth. Both the in-phase and quadrature response were collected. The in-phase is important as it highlights the location of many of the marked graves that contain metal.

As at Koukourarata, lines were repeated after interludes in the survey to monitor for any drift.

4.3.1.3 Data Processing

Exactly the same method of processing was applied to the Wairewa data. The files were converted and imported into an Excel spreadsheet. The data were corrected by subtracting the median for each line.

The data were then imported into Surfer. A residual file was created by subtracting a large scale trend from the original plot, however, this tended to remove some of the detail (App. I). Unlike Koukourarata, the masking effect was a result of cultural influences such as fences, graves and vegetation rather than basement geology.

4.3.2 Magnetometer/Gradiometer

There were many problems in conducting the magnetometer/gradiometer survey at Wairewa. The survey period was prolonged and problems with the machinery meant the surveys had to be suspended and then completed some time later.

4.3.2.1 Survey Design

The magnetometer survey was carried out over the majority of the site. The lines were shortened to approximately 30 m so the survey area did not include the new area of the urupa. Previous to the field-work, the Wairewa runanga representatives indicated that the excluded area was not known to contain any graves. The excluded area was also heavily influenced by the presence of modern concrete capped graves, which would have been likely to deteriorate the quality of results.

The survey line spacing and station spacing were once again kept consistent with the EM survey. A position for the base station was selected at the base of the slope. This location was chosen as it was as remote from cultural influences as could be achieved.

4.3.2.2 Data Collection

The circumstances surrounding data collection at Wairewa were challenging. The initial survey was into the fifth day when the instrument failed. The survey was resumed approximately one month later.

There was an error made in setting out the grid for continuation of the survey. The survey area continuation was skewed had been skewed (Fig. 4.5). The new orientation of the survey lines meant that a section of the survey had to be repeated to ensure the entire area was surveyed. This took at further 2 days to complete.

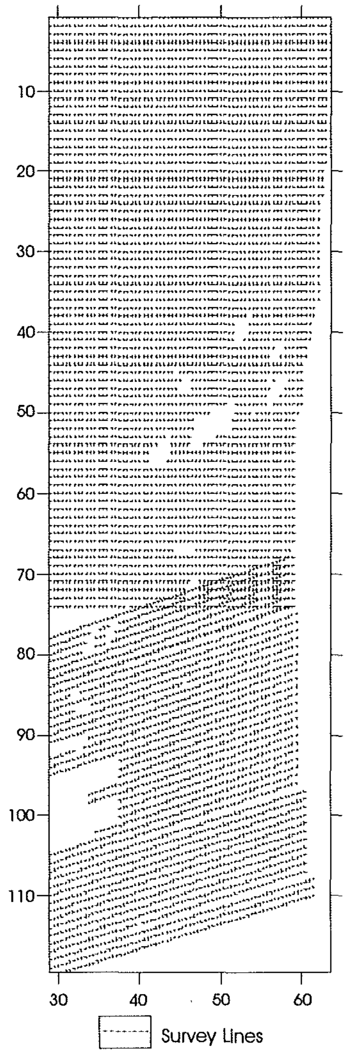


Fig. 4.5 : Survey lines at Wairewa. The orientation changes due to an error in the layout. The areas not surveyed are obstructed by trees or graves.

4.3.2.3 Data Processing

The data were downloaded from the logger and imported into Excel. The gradient was calculated in the same manner as for the Koukourarata data.

The elapsed time was calculated against the base station readings (Fig. 4.6). This allowed for correction of the survey data relative to the background magnetic field.

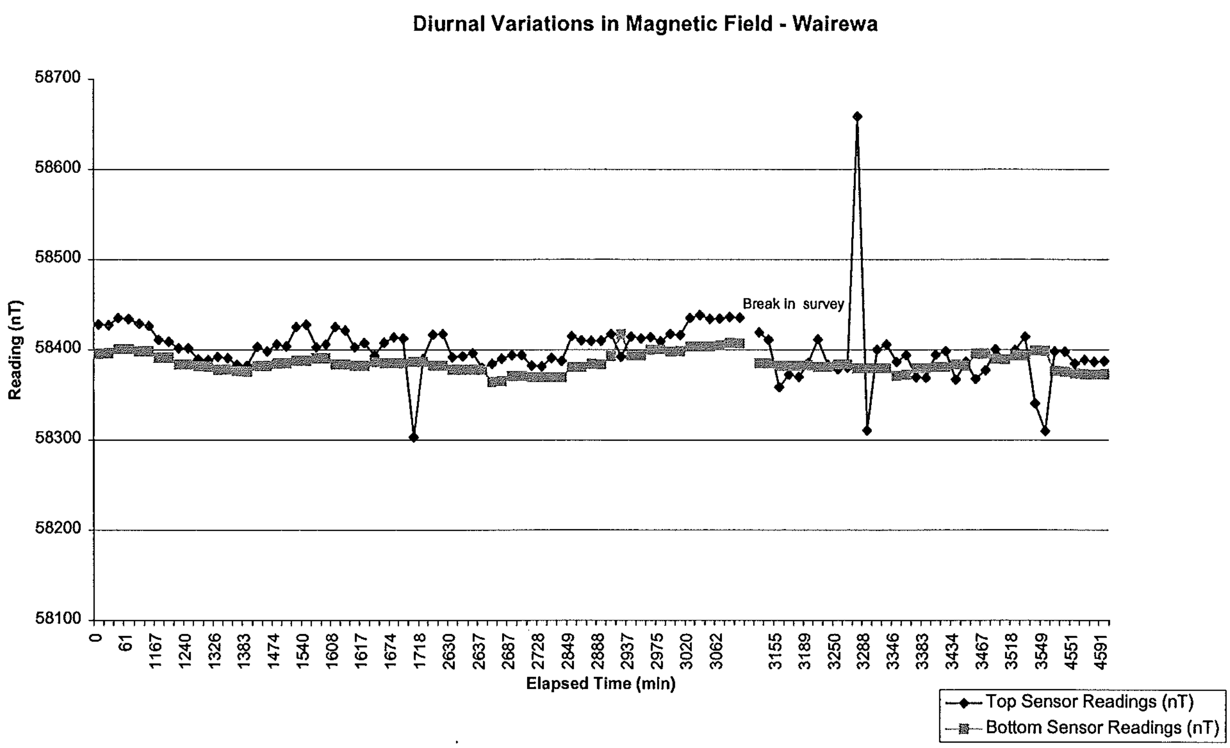


Fig. 4.6 : Graph shows the diurnal variations that occurred throughout the magnetometer/gradiometer survey at Wairewa. The break in survey indicates a month break in time due to equipment problems, where was the lapsed time is indicative of actual survey running time.

The spikes in the base station readings only occurred for one sensor and thus were removed and not corrected for as the base level is seen to be otherwise consistent.

Due to the error in survey layout, the actual line and position of each reading had to be calculated in relation to the original survey grid. Basic trigometric functions were used to establish the correct station positioning.

There was a large break in time between the commencement and completion of the survey. Therefore when elementary Surfer plots were created the different parts of the survey could be clearly seen in the gradient data. To remove this phenomenon the median value was calculated for each line and then removed from the readings for that line. This removed any significant changes in base level. Repeated lines were then plotted against one another to check for satisfactory correlation. Correlations were found to be excellent (Fig. 4.7).

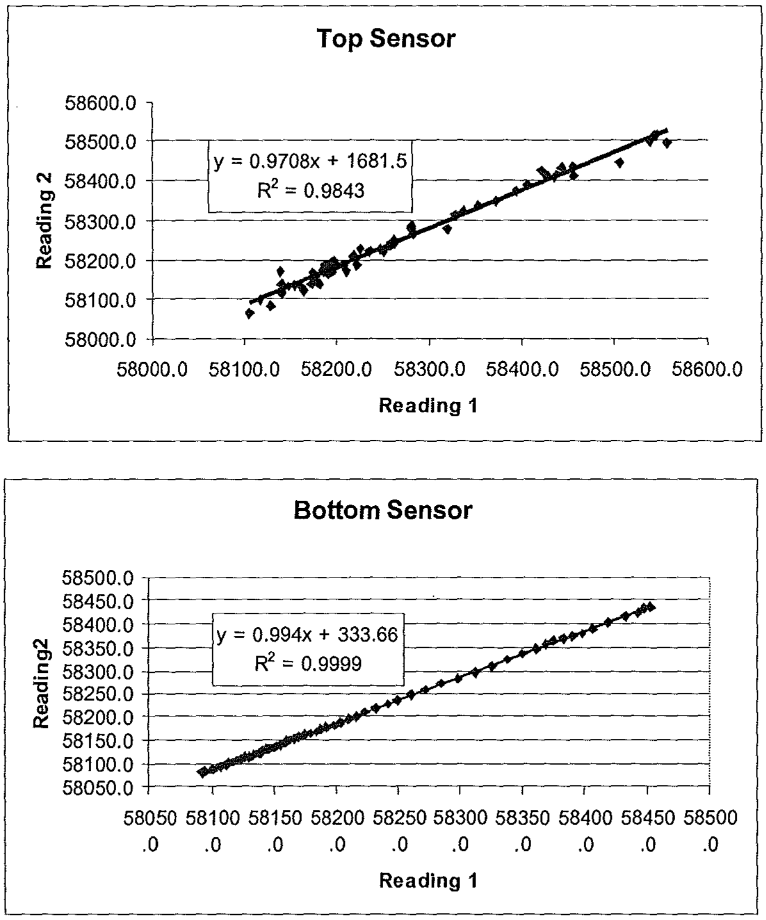


Fig. 4.7 : Correlations between repeat lines after base station corrections had been completed were excellent.

4.3.3 GPR

4.3.3.1 Survey Design

It was decided that two areas should be surveyed with the GPR. The entire lower section was chosen as there were relatively few marked graves in this area and some significant anomalies were present in the raw EM and magnetometer data. 121 lines were surveyed at 0.5 m line spacing; readings were recorded in 0.05 m increments.

The second area consisted of 21 survey lines. It extended from the area containing the majority of graves, up the slope to a pine tree. The survey ceased at the pine tree because one of the elders of Wairewa Runanga remembers from his childhood that a fence used to enclose the old urupa at this location (Panirau, pers. com., 2002).

4.3.3.2 Data Collection

Due to the shear size of the site, both grids were surveyed only with the 225 MHz frequency system. There was an additional line shot using a 400 MHz frequency antenna, purely as a basis for comparison of attenuation of signal at differing frequencies.

A CMP profile was carried out in order to obtain a value for velocity. This was conducted at the base of the upper grid in an area that was relatively flat lying and thought to be representative of the survey area as a whole.

4.3.3.3 Data Processing

Once plotted, it was found that the common mid-point (CMP) profile (Fig. 4.8) was not large enough to obtain an accurate velocity measurement by manual calculations. Therefore, the data was entered into the winEKKO™ programme, so that semblance velocity analysis could be carried out (Hatton *et al.*, 1986). The semblance process aligns the traces and calculates the average power, from which the velocity at which the curved reflectors flatten can be obtained. The velocity for the Wairewa site was determined to be 80 m/μs. This number is similar to the 0.07 m/ns expected velocity value for silts provided in the pulseEKKO software (Sensors & Software Inc., 1993).

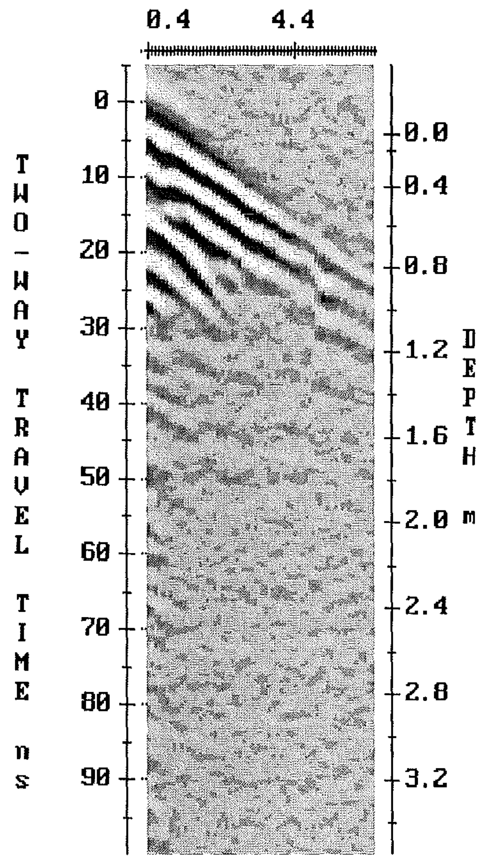


Fig. 4.8 : CMP profile from Wairewa survey. The profile is not long enough to obtain a reliable velocity reading manually.

Only very limited data processing was required. A DEWOW filter was applied. There were no migrations carried out so as not to flatten the diffractions. Once again the survey lines ran parallel with the slope, therefore no topographic corrections were required. There was no requirement for rubber-banding as the 225 MHz frequency system was triggered using an odometer rather than running in continuous mode. The 400 MHz frequency data were processed in exactly the same way.

CHAPTER 5 : RESULTS AND DISCUSSION

5.1 INTRODUCTION

The results of this investigation are best described as variable. The results and interpretations are presented in this chapter. Each technique will be discussed individually, considering results from both sites. A synthesis of results for each site is then presented. Conclusions summarising the findings appear in chapter 6.

It was hypothesised that the disturbance of the ground caused by a burial of a human would result in changes in subsurface. Disturbance of stratigraphy and changes in the subsurface moisture content could affect the electrical and dielectric properties of the subsurface. There may also be a variation in the local magnetic field due to disturbance of minerals in the soil layers. It was not known prior to this survey what response, if any, would result from burials in possibly moderately conductive loess soils.

5.2 EM SURVEY

5.2.1 Koukourarata

5.2.1.1 Results

The results of the EM survey at Koukourarata are presented in Fig. 5.1. The colour scale is indicative of the relative conductivities. The white end of the spectrum represents the highest conductivity values, while the lowest readings are indicated by blue colours. The raw apparent conductivity ranges from 7 to 30 mS/m, whereas the residual values lie between -4.5 and 7 mS/m.

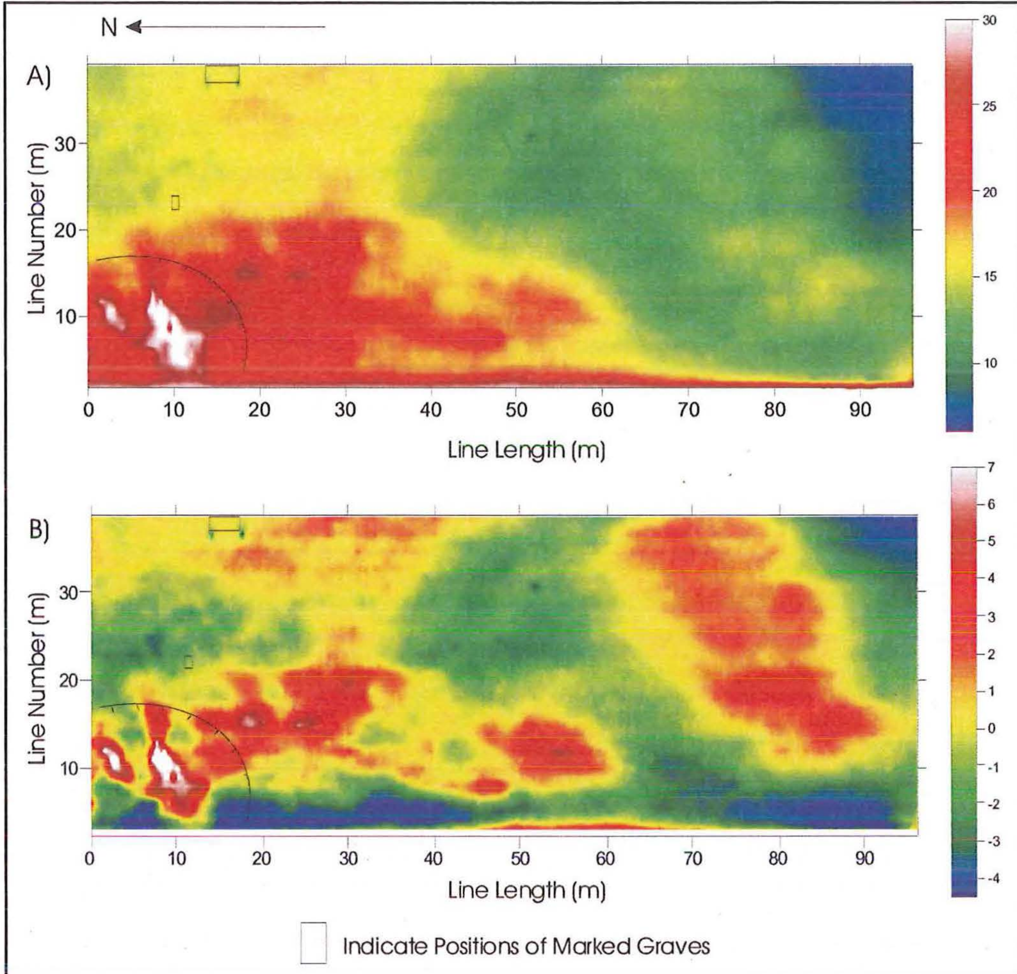


Fig. 5.1 : A) Raw apparent conductivity plot B) Residual conductivity data. Significant features have been marked. The curved line represents the scarp of the slump. The colour scale is in mS/m.

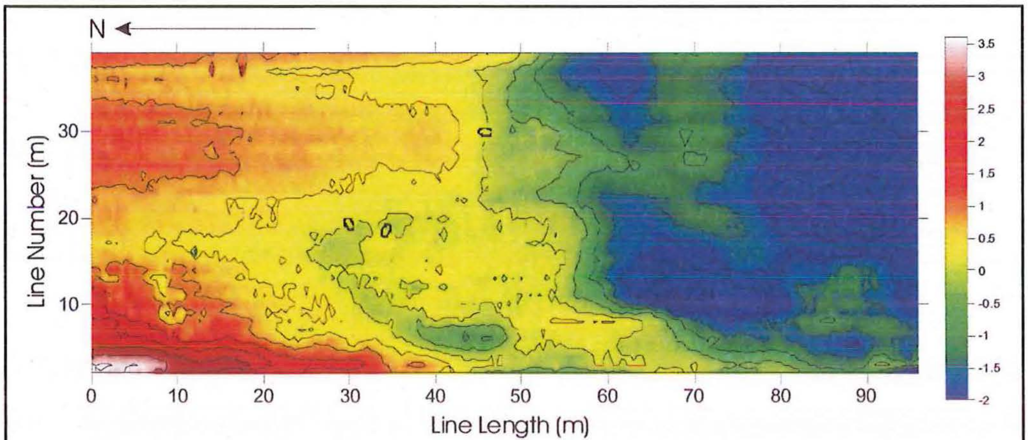


Fig. 5.2 : In-phase readings from Koukourarata site. The data mirror the topography closely. The colour scale is in ppt.

The broad trend in conductivity values is mirrored by the in-phase readings (Fig. 5.2). High conductivity readings are at the northern end of the site. This indicates that the quadrature mode is influence by a dominant background trend. Attempts to attain a residual plot improved the quality slightly but were not wholly successful at removing the larger scale trend.

5.2.1.2 Interpretation

The in-phase data closely mirror the topography of the site. The quadrature readings display a similar trend. There is a rise in elevation of the land at the northern end of the survey area that is analogous to the rise in conductivity. Therefore, it is interpreted that the larger background trend in the EM data is a direct result of the underlying bedrock. The rise in land is likely to be a bedrock high with a thinner cover of loess material. The loess in relation to the bedrock is moderately resistive.

There is a gully to the south of the site. The dark green area in Fig. 5.1.A lies adjacent to the gully. It is thought this may be a gully infilled with loess from stream avulsion. There are regions of higher conductivity (yellow) within this area. These were of interest as they may be indicative of changes in the moisture content of the subsurface, caused by disturbance of the soil structure (such as a burial). Another possibility is there may be boulders of more conductive bedrock in the old stream channel carried from the source area. Due to the sacred nature of the site, excavations are not possible. Therefore, it was decided that the GPR survey would be run in this area in an attempt to resolve the ambiguity.

The slump in the north-west corner of the survey area shows clearly on both the quadrature and the in-phase plots. This is likely to be a result of survey technique. The ground was rough, broken and on a slope, thus during the survey, the ends of the boom were at times very close to the surface of the ground, yielding higher conductivity readings in this area. The soil mantle is disturbed in the area leading to the changes in the subsurface moisture content. Results from this region are not considered reliable; however, it is unlikely that a grave would be located on a steep surface prone to slumping.

The marked grave enclosed in a fence was clearly indicated by the EM survey, due to the presence of conductive barbed wire. The mildly resistive green spots are the wooden corner posts of the fence. The second marked grave did not show on the survey but the general area in the north-eastern sector of the grid appears to have a mottled appearance due to varying conductivities.

5.2.2 Wairewa

5.2.2.1 Results

The quadrature readings from the EM survey at Wairewa are shown plotted in Fig. 5.3.A. The conductivity is represented by a similar colour scale to the Koukourarata data. The raw apparent conductivity ranges from 0 to 20 mS/m.

The background appears to be relatively uniform. A residual plot was created in an attempt to minimise significant influences from trees and marked graves that may be masking any other anomalies (App. I) however, this had the effect of removing some of the detail therefore, the raw data has been used. The plot of the in-phase readings (Fig. 5.3.B) shows the areas where these effects from the presence of metal are greatest.

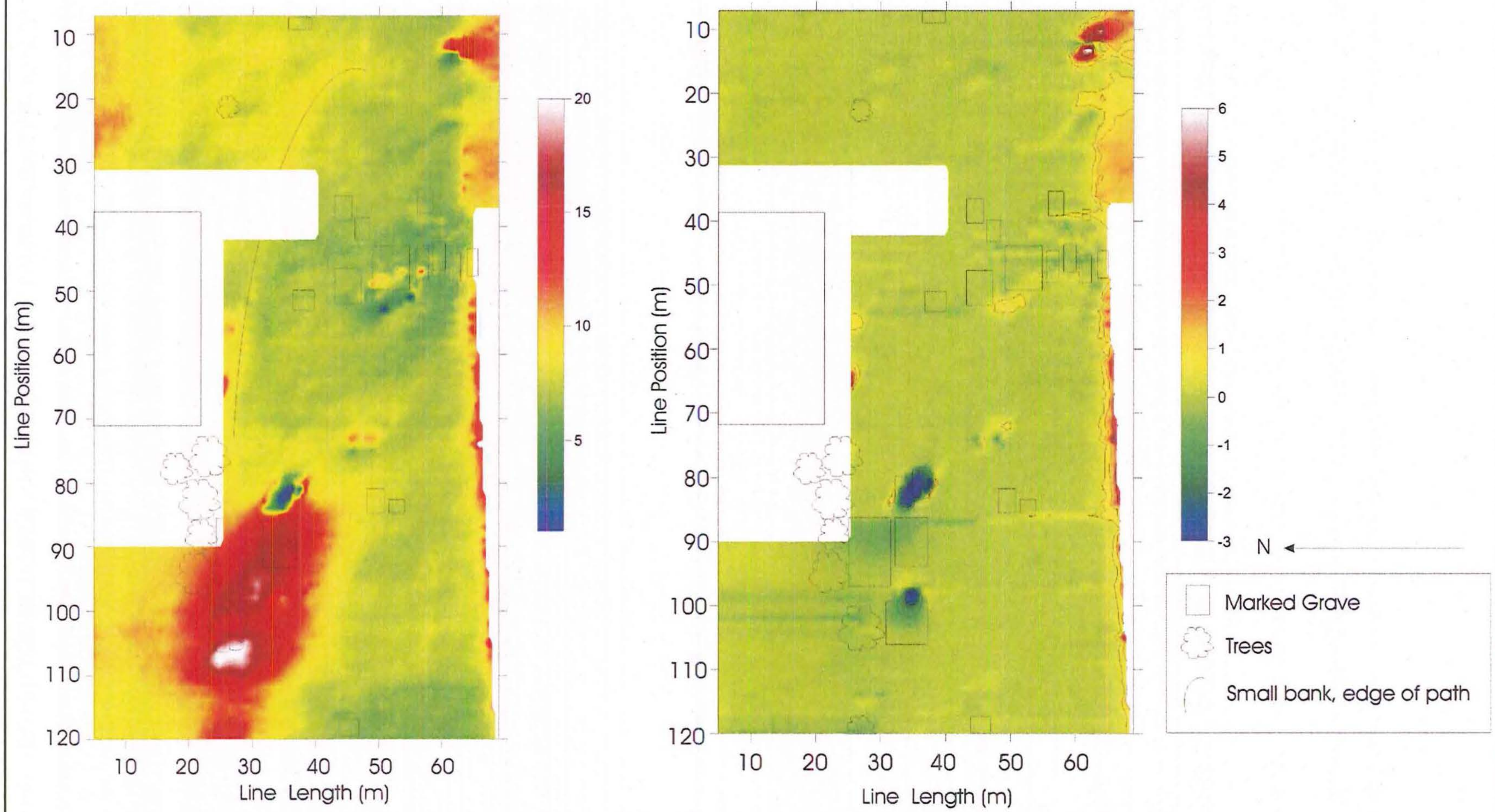


Fig. 5.3 : A) Raw apparent conductivity data at Wairewa site. (Measured in mS/m). B) In-phase component of EM survey (measured in ppt). Marked graves and trees have been indicated on the plots.

5.2.2.2 Interpretation

The in-phase plot (Fig. 5.3.B) shows clearly the areas of high metal content. The fence on the southern edge of the grid and some of the marked graves clearly influence the results. Fig 5.4 shows that the quality of the bulk conductivity readings are greatly affected by the presence of metal. Data quality improves away from these influences (App. III). Some of the marked graves are enclosed by iron fences, iron is electrically conductive. Other graves contain reinforced concrete. These influences are also present in bulk conductivity readings. Some of the marked graves are enclosed by iron fences. It is likely that others contain reinforced concrete. There is an influence detected from some of the trees. This is likely to be associated with changes in subsurface moisture content in the areas surrounding the trees.

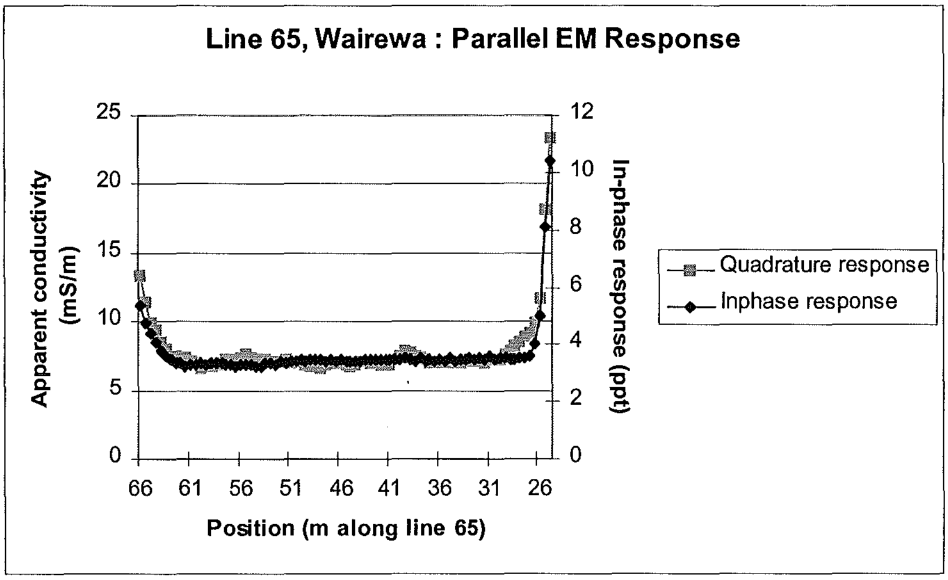


Fig. 5.4 : The close correlation between the two lines shows that the quadrature component is heavily influenced by the presence of metal.

There is an interesting additional anomaly present on the conductivity maps. The pairs of dipolar features occurring on lines 72 to 75 between 45 and 50 m are also present as small anomalies on the in-phase data indicating the possibility of buried metal. There is some texturing occurring around the rest of the area but no other individual anomalies are visible.

The presence of the loess soils does not appear to have significantly affected the results. Unlike Koukourarata, the bedrock lies past the penetration depth of the EM31. The presence of the slope has not deteriorated the quality of the results, as the background conductivities are similar over the entire site.

5.2.3 Summary of EM results

The EM31 survey was useful as a reconnaissance survey technique to identify areas of interest that required more detailed surveying. The survey results were not degraded by the presence of possibly moderately conductive loess soils. However, geological factors were found to be a problem in Koukourarata as the bedrock was conductive and significant influenced the results.

The EM instrumentation was found to be sensitive to numerous other features. It clearly showed large scale ground displacement. The presence of good conductors such as fences and reinforced concrete was clearly evident in the final results this was evident at both sites. The survey at Wairewa showed that vegetation also has the potential to effect conductivity values. This is can probably be attributed to changes in the subsurface water content.

5.3 MAGNETOMETER/GRADIOMETER SURVEY

5.3.1 Koukourarata

5.3.1.1 Results

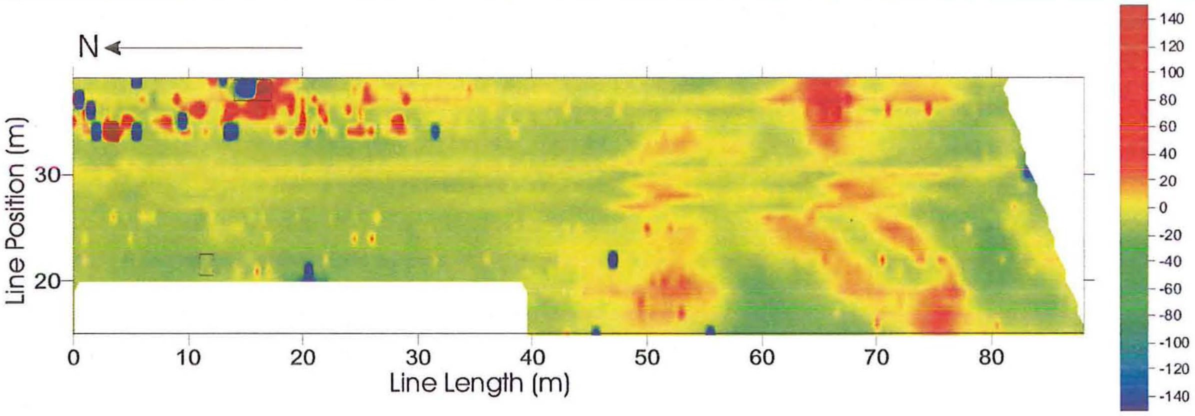


Fig. 5.5 : Vertical gradient data plotted and calculated from top and bottom sensor readings (App. I). (Colour scale is in nT/m).

The magnetometer/gradiometer survey of Koukourarata was successful in delineating anomalous areas. The vertical gradient is displayed in Fig. 5.5, this is sensitive to near-surface features as described in chapter 3. The colour scale is indicative of the changes in magnetic susceptibility. The gradient ranges from -140 to 140 nanoteslas per metre (nT/m).

Time restriction did not allow the most westerly 15 lines to be surveyed. This was not thought to be significant as the slumped area was discounted as a possible locality for graves and the radar was to be carried out throughout the rest of the area.

There is some discontinuity across the grid. The survey lines running north-south are evident. Attempts made to remove the strips were unsuccessful, therefore the raw data have been displayed. The areas where data collection was insufficient to infer results have been blanked.

5.3.1.2 Interpretation

Aside from disturbance by the survey lines the southern end of the magnetic plot shows the same general trend as the EM data. The red, patchy area is the region assumed to be a loess infilled valley.

There is an area that appears to have undergone much disturbance in the north-east corner of the plot. There are often magnetic highs adjacent to a low, this can be seen in the position of the marked grave and is due to the dipolar effect. This type of response has been found from graves in previous studies (Nobes, 1999). The region of disturbance continued to the northern and eastern edges of the grid, it was decided to extend the GPR survey in these directions.

5.3.2 Wairewa

5.3.2.1 Results

The magnetic gradient at Wairewa is displayed in a similar manner to the data from Koukourarata (Fig. 5.6). The gradient values are higher at Wairewa. This is likely to be a result of the presence of magnetic metal, such as iron, at the site.

The newer area in the northern portion of the urupa was not surveyed. This was not thought to contain any unknown burials. It was also likely that the presence of the heavily adorned marked graves would deteriorate the quality of results.

The presence of most of the marked graves shows clearly. These often display the expected dipolar response. The response is more obvious for the more elaborate graves which are likely to contain metal. The marked graves appear to be on a diagonal line on the image maps, although they appear in a straight line on the surface of the ground. This can be explained by the curvature of the slope along which the survey lines were directed.

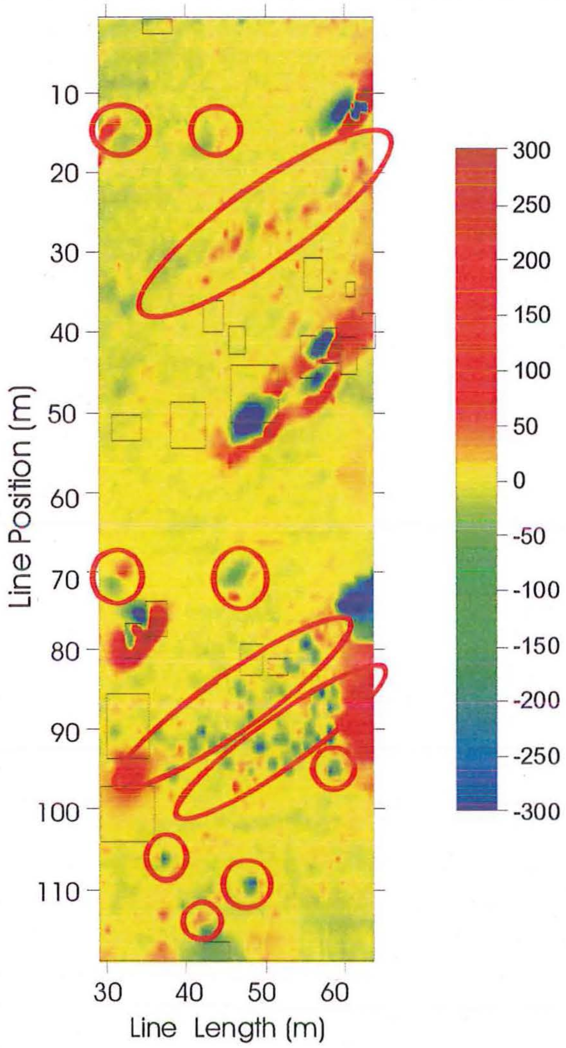


Fig. 5.6 : Vertical gradient data plotted and calculated from readings from the top and bottom sensors. The red oval indicate areas of aligned anomalies interpreted to be likely positions for unmarked graves. (colour scale in units of nT/m).

5.3.2.2. Interpretation

Fig. 5.6 shows many anomalies that are not attributable to the presence of marked graves. Many of these anomalies are aligned, they are highlighted by the presence of red ovals in Fig. 5.6. The alignment appears to be diagonal but follows the natural curvature of the slope. These aligned anomalies are interpreted from the magnetometer/gradiometer data to be likely locations of unmarked graves. Some of these anomalies are present in the maps of the data from the individual sensors (App. I). However, it is logical that the anomalies would show more clearly in Fig. 5.6 as the vertical gradient is more sensitive to near surface features.

Fortunately, the magnetic survey was less influenced by other cultural features than the EM. The presence of the boundary fences was not as obvious because they were composed of aluminium which is a non-magnetic metal. The position of the trees can not be delineated at all as the magnetometer is not usually sensitive to changes in subsurface moisture content.

5.3.2 Summary of magnetometer/gradiometer results

The data obtained from the magnetic surveys is useful. The survey at Wairewa showed that the quality of the data is affected by the presence of the marked graves. Masking of smaller anomalies may occur in the areas which showed a large magnetic response from cultural items. There was not as much interference at Koukourarata, the presence of the power lines did not affect the investigation.

As with the EM, the magnetic survey at Koukourarata was affected by subsurface geology. However, in general the data obtained from the magnetic surveys was of higher quality than the EM data at both sites. The magnetometer/gradiometer was less susceptible to cultural influences such as fences. Therefore, a clear idea of the areas in which to concentrate the GPR investigation was gained.

5.4 GPR SURVEY

5.4.1 Koukourarata

The GPR survey at Koukourarata was carried out on two separate grids. These were the areas identified by the previous survey techniques as regions that may require further investigations. The upper grid was located on the platform at the top of the rise up from the shore; this area contained the two marked graves. The lower grid was located between the two Ngaio trees on the lower planar area.

5.4.1.1 Upper Grid Results and Interpretation

The upper grid was surveyed with the 225 MHz frequency system. There were numerous diffractions evident in the profiles (App. IV). A grave facing east-west would yield diffractions over approximately 4 lines (assuming a grave is on average 2 m in length). There were six occasions on which diffraction were continuous through four or more lines and a further seven localities where they continued through three lines (1.5 m). It has been discovered in previous studies that the head end of the grave often has a stronger response (Nobes, 1999), this may also be the case.

The marked grave can be seen on the profile, however, the response was not as clear as some other diffractions present (Fig. 5.7).

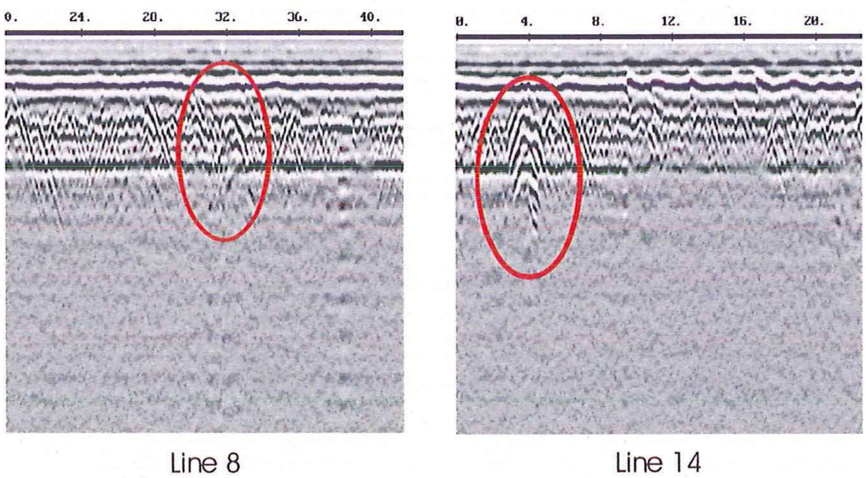


Fig. 5.7 : Comparison of segments of two upper grid profiles showing the diffractions present. The diffraction highlighted in line 8 is the location of the grave marked with a headstone. The diffraction present in line 14 does not have any surface expression and is continuous over 1.5 m.

Owing to the fact that not all diffractions showed with clarity in the profiles, it was decided to attempt further qualitative analysis. Each survey point was assigned a value from 0 to 3 corresponding with the likeliness of that locality to contain a grave. A position assigned a number 3 was very probably a grave with clear diffractions continuous over 3 or more lines. The number 2 was probable with some evidence of diffractions continuous over three or more lines, or clear diffractions continuous over 2 lines. A locality assigned a number 1 was the possible location of a grave where some diffraction or break in trend was observed; this may or may not have been continuous over more than one line. A position allocated a 0 had effectively no evidence of disturbance. Once values had been assigned these were plotted onto a surface map (Fig. 5.8) showing the most likely localities of graves according to the 225 MHz GPR survey.

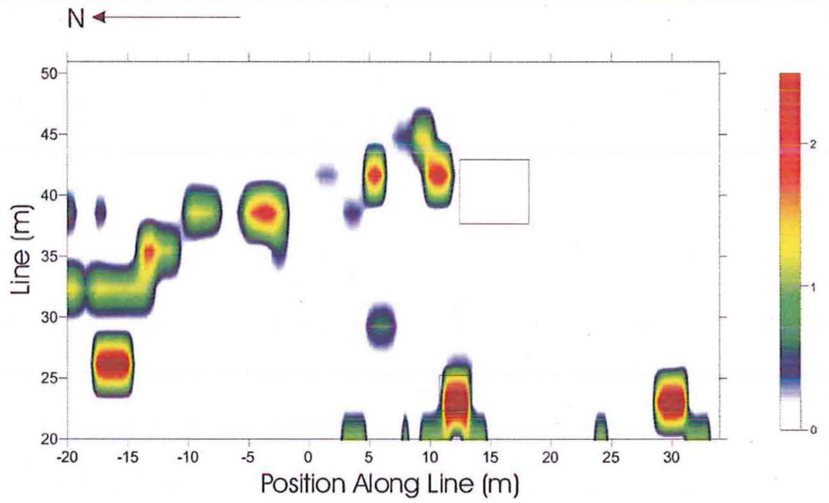


Fig. 5.8 : Surface map showing results from qualitative GPR analysis. The red indicates the most likely position for a grave, the white is very shows that the area is very unlikely to contain a grave. The area is numbered according the original grid. The positions of the marked graves have been shown; the larger grave could not be surveyed due to the fence.

There were no diffraction patterns seen in the upper 5 m suggesting the location the urupa boundary. There were some anomalies clear at the northern edge of the profiles; therefore, it would be recommended that the boundaries of the urupa be extended slightly north to the break in slope.

5.4.1.2 Lower Grid Results and Interpretation

The lower grid was surveyed with both the 225 and 200 MHz frequency radar systems. There were many diffractions evident in the 225 MHz frequency results. The majority of these were continuous over two lines; there were five localities where diffractions were carried over three lines and a further four areas where patterns were seen to be consistent over four or more lines (2 or more meters). The ranking system was utilised for this area also in an attempt to interpret the random anomalies (Fig. 5.9).

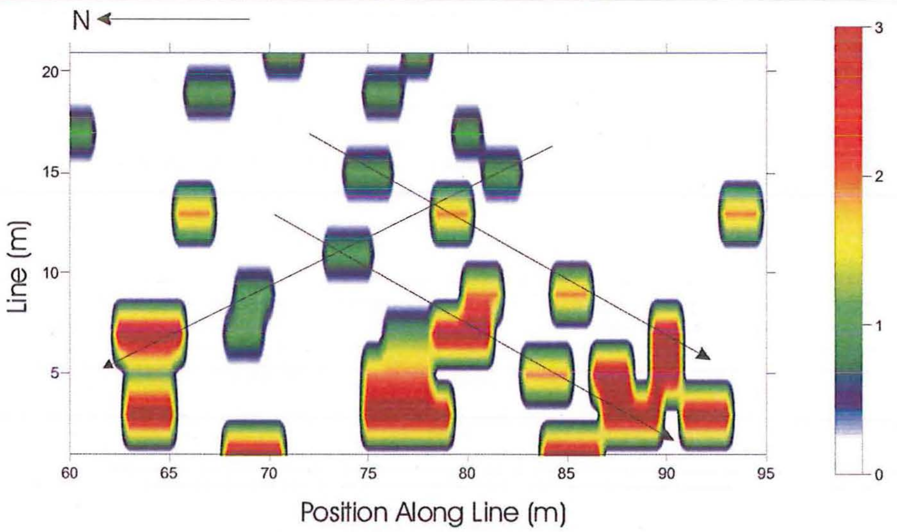


Fig. 5.9 : Surface map of the interpreted GPR profiles. The deep red indicated that there were clear diffractions evident over a number of lines. The arrows that have been superimposed on the map indicate a difference in alignment possibly due to deposits from an old channel.

Almost all diffractions occurred in the lower 10 m of the survey grid, closest to the shore. There are three alignments that can be recognised when interpreting Fig. 5.10. The clear diffractions appear to have a fabric oriented north-south; this may be a result of alignment of burials. There are many diffractions located close to one another, therefore the idea of a mass grave was proposed, possibly dating back to a conflict or epidemic.

However, it must be considered that the orientation of survey lines is often visible in geophysical results due to the discrete nature of the survey lines. There are other fabrics evident on the surface map. There are diagonally trending alignment of the diffractions, identified on figure 5.10 with black arrows. This could therefore be further evidence of an old stream deposit containing many boulders of volcanic bedrock, though from the radar data it is difficult to interpret which direction the stream was flowing.

The 225 MHz frequency results were ambiguous, therefore the lower resolution pulseEKKO 100 results (App. IV) were analysed in an attempt to provide some clarity. The results are banded, however this does not effect the legibility of the profiles. The response from the gully at the southern end of the survey was evident and continuous throughout the profiles.

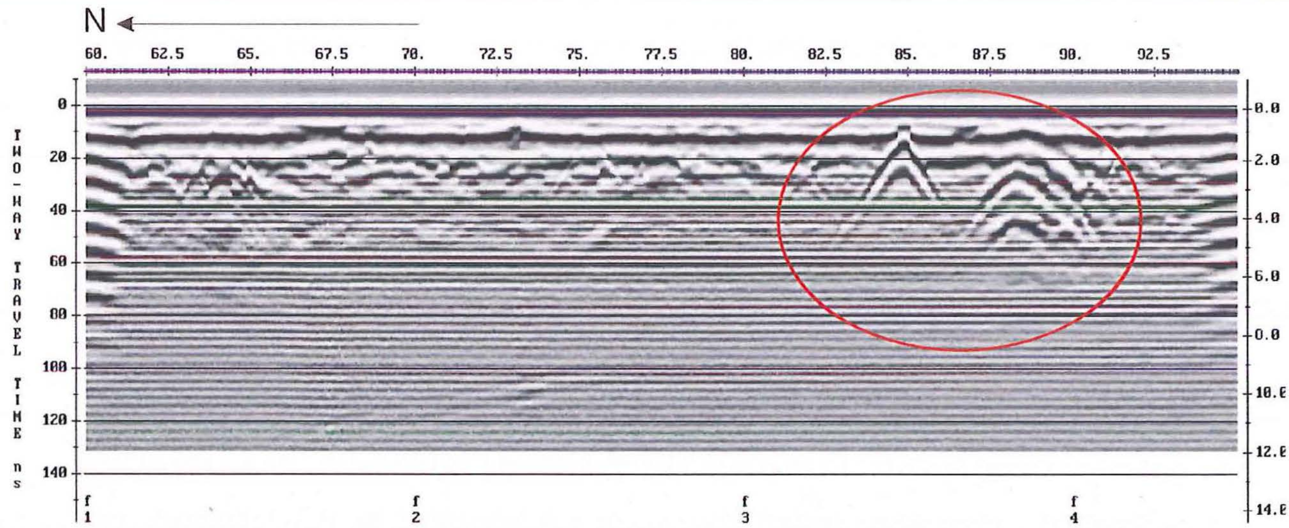


Fig. 5.10 : Line 17 of the 200 MHz frequency lower grid survey. The red oval shows the position of two broad diffractions. The diffraction at the southern end of the grid is the response from the gully. The diffraction at the northern end is likely to be the result of a metal survey peg.

However, there were a number of clear diffractions evident. In two localities there was the presence of diffractions continuous over four or more lines and a further four positions where diffractions were visible over three lines. However, it was surprising that there was not a clear correlation between anomalies seen on the 200 MHz frequency profiles to those identified by the 225 MHz GPR survey. The diffractions also appeared to be broader, spanning about 5 m in length along the line (Fig. 5.10).

The inconsistencies in results of the two surveys conducted is thought to be due to the differences in the two systems. The pulseEKKO 100 ran on continuous mode and therefore positioning is likely to be less accurate than the odometer. This system was also mounted on a toboggan which was difficult to operate on the sloped ground. Therefore, line positions may not be entirely accurate. The pulseEKKO 100 ran with fibre-optic cables, where as the 225 MHz frequency system had shielded coaxial cables, this too my have contributed to discrepancies in survey results. The systems also ran from different sized power supplies.

This initiated the idea that, if there were graves present in the lower grid, it may be possible that they are oriented north-south, parallel with the survey lines. If this were the case then one would expect a broad diffraction only spanning two lines.

5.4.2 Wairewa

As at Koukourarata there were two surveys completed. The lower grid covered half of the plot area. The upper grid only consisted of 10 m of survey above the area where most of the marked graves were contained.

5.4.2.1 Lower Grid Results and Interpretation

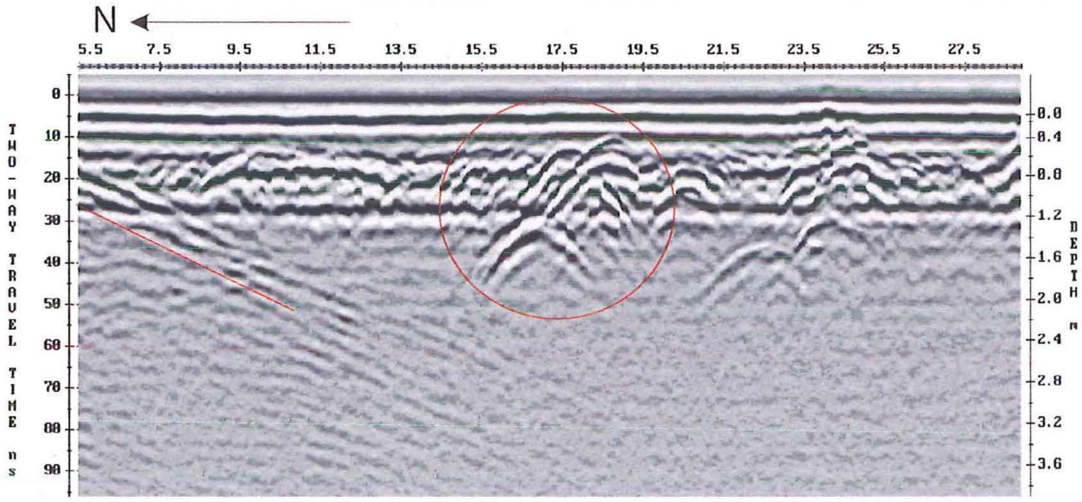


Fig. 5.11: Line 59 on the lower grid at Wairewa. The diffractions indicated by the red circle are caused by the two marked graves adjacent to one another in the centre of the lower plot area. The red line shows the airwave, due to the influence of trees and other graves at the end of the profile.

The area was surveyed with the 225 MHz GPR system. There were many diffractions evident in 121 survey lines (App. V). The majority of the marked graves were represented by very clear diffractions (Fig. 5.11).

The airwave caused by the presence of the trees or other marked graves can be seen at the northern end of almost all of the profiles. There were occasions where ringing occurred throughout the profiles due to the presence of metal on the surface. Surprisingly the quality of the signal was not affected by the presence of the fence at the southern end of the profiles.

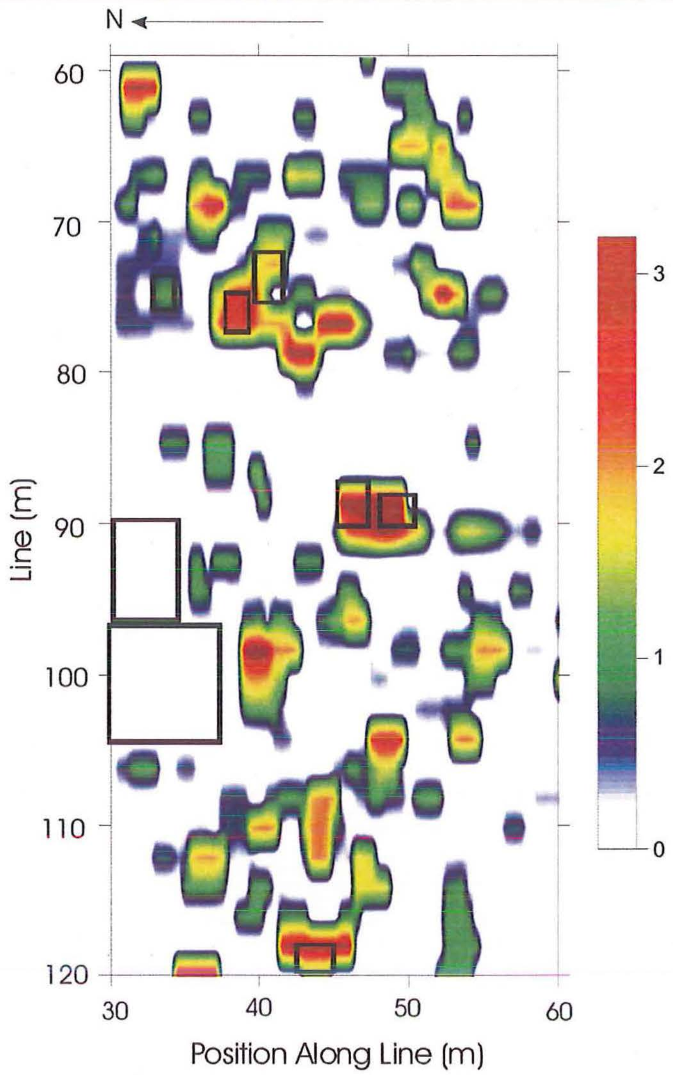


Fig. 5.12 : Surface map of the interpreted GPR readings for the lower grid at Wairewa. The marked graves were clearly evident in most cases. The two marked graves at the northern edge of the area where not surveyed as they were enclosed in small fences.

As there were many profiles it was thought that the best approach would be to adopt the ranking system for the data and create a surface map that could be compared to the magnetometer/gradiometer and the electromagnetic data (Fig. 5.12).

The results of the techniques must be compared (section 5.5) before there can be inference about the likely locality of burials.

5.4.2.2 Upper Grid Results and Interpretation

The upper grid area consisted of only 20 survey lines. There were still several diffractions evident that have been represented in a surface map (Fig. 5.13). GPR is a good indication of the likely position for a graves.

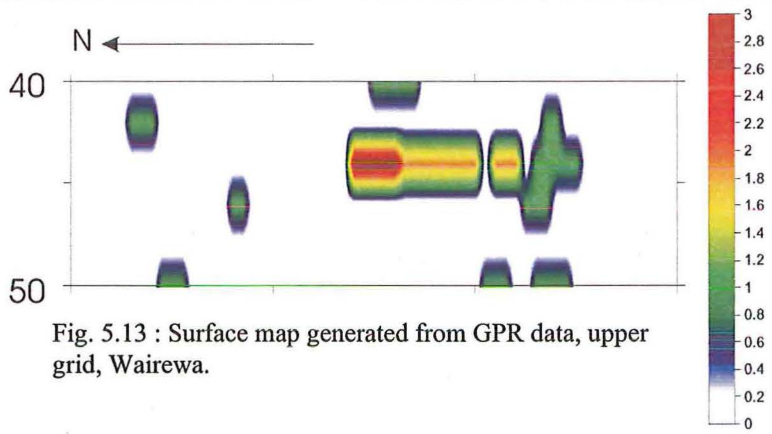


Fig. 5.13 : Surface map generated from GPR data, upper grid, Wairewa.

5.4.2.3 Frequency Comparison

As a basis for comparison, two lines were run using a 450 MHz antennas, with a system identical system to the 225 MHz system. Fig. 5.15 shows a repeat of Line 110 in the using the differing frequencies. The 450 MHz frequency results in a higher resolution image, however, the profile yields less information, which is consistent which previous studies (Smith & Jol, 1995, Nobes, 1999). Diffractions are somewhat collapsed and are therefore more difficult to identify. As is consistent with GPR theory, the higher frequency signal is more susceptible to ringing, as is seen on the profiles.

The depth of penetration varies. A lower frequency signal will penetrate the ground further. In this case, the 225 MHz frequency reflections were still being received at a depth of 1.2 m, whereas reflections are only evident to 0.8 m in the 450 MHz frequency profile.

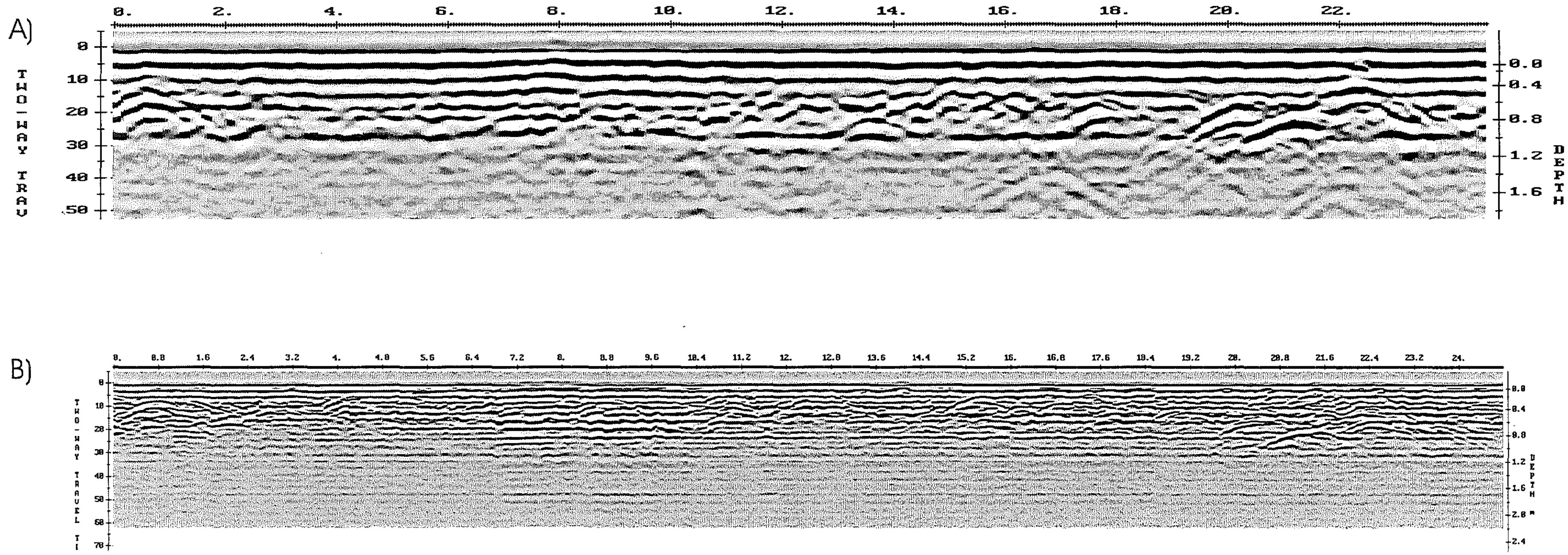


Fig. 5.14 : The two profiles were shot along Line 110. A) the 225 MHz frequency system was used B) Shot with the 450 MHz frequency system. There is greater resolution using the higher frequency instrumentation not as much information can be obtained as diffractions are collapsed, penetration depth is reduced and there is the presence of banding.

5.4 Summary of GPR results

GPR is a useful tool in investigation of the subsurface. The quality of results was relatively good. Diffractions patterns could be identified for all marked graves surveyed at both sites. The presence of marked graves did not mask the ground response surrounding the grave. Attenuation of the radar signal was sufficient at both sites despite problems associated with geological factors in earlier surveys.

It is interesting that results from the survey at Koukourarata combining the 225 MHz and 200 MHz frequency techniques did not correlate. However, the survey was conducted on a large scale and the two system were run differently (one attached to an odometer and the other in continuous mode) therefore, the discrepancies in data collection may be attributed to differences in positioning. It is believed that GPR is a very reliable, effective tool for this sort of investigation if operated correctly and consistently.

5.5 COMPILATION OF RESULTS

Geophysics provides a means for identifying anomalous areas; the anomalies identified may or may not be associated with the target of the investigation. Therefore, the most effective way of achieving the reliable results is to combine the data obtained from the use of a variety of geophysical techniques. This section displays the attempts to pull together the results from the EM, magnetometer/gradiometer and GPR surveys conducted at Koukourarata and Wairewa, and to present a summary of the findings. Map 1 displays finding for Koukourarata survey. Map 2 shows results from Wairewa.

5.5.1 Koukourarata

It is difficult to obtain a comprehensive summary of the techniques when the different techniques were utilised in different areas of the grid. It was the initial intention to produce an 'occupancy map' (Nobes, 1999) to locate the most likely localities for a burial through to highly unlikely locations. However, because the three techniques only overlapped in a very small area this was not achievable.

The initial investigation using the EM identified the areas that required further surveying. The use of the magnetometer/gradiometer reinforced these findings. This resulted in the definition of two grids for the GPR survey. The results of all of the geophysical techniques used on the upper grid area are displayed in map 1.

The results were moderately successful. It is felt with relative confidence that a fence may be erected enclosing the urupa. The eastern boundary of the urupa can be defined approximately 46 m up from the shore side fence-line, as was most clearly defined the GPR surveys. The southern boundary is thought to be the edge of the GPR survey grid, as defined by the magnetometer and EM surveys. It is recommended the western edge of the urupa be extended to the head of the slump. Unfortunately, the northern boundary does not display the same clarity. Anomalies continue to the northern edge of the EM and magnetics surveys; this was the reason for extending the GPR investigation. However, diffraction patterns are present on the northern edge of some of the profiles. Therefore, it is recommended the northern fence line run parallel to the slope break.

There were some very interesting results obtained for the lower grid area (Map 1). The grid was identified as an interesting area due to a mottled appearance in the EM results. The high conductivity response at the western end of the EM results is directly related to the presence of the fence. It was the intention to carry out the magnetometer/gradiometer survey through this area but due to time constraints, only a partial amount of the survey was completed. Therefore the GPR results had to be relied upon to resolve ambiguous anomalies.

The two possible scenarios have been discussed in the interpretation of the individual results. The GPR results show the presence of many clear diffractions closer to the shore. This was an area that was determined to be conductive. The conductive areas were anomalous in an area that was dominated by moderately resistive material. This lead to the formation of the theory that the moderately resistive material was a loess filled gully, shown previously to be resistive in contrast to the conductive bedrock. The area lies adjacent to the present site of a stream containing some large bedrock boulders up to 1.5 m in length. It is proposed that the stream has avulsed and the anomalies and diffractions identified can be attributed to stream boulder deposits.

The theory works well, if the north-south alignment of GPR diffractions are ignored. This may be inherent from the survey geometry. The diffractions could also be attributed to burials. Some diffractions are continuous over 2 m in length; it is unlikely that boulders of this size exist in this area. When examining the 200 MHz frequency GPR data, there are some very broad diffractions that are only continuous over one or two survey lines; these may possibly be the result of a burial trending in the same direction as the survey lines. However, the location of the site as a burial ground and a north-south orientation of graves is not consistent with Maori tradition. The site is on relatively low lying ground situated separate to the locality containing the marked graves. However, the location of the two Ngaio trees is a puzzling coincidence as Ngaio trees were traditionally planted at the corner of urupa.

Although it is viewed as unlikely that the lower grid area is the location of a Maori burial site, with the results obtained it is impossible to discount this entirely.

5.5.2 Wairewa

It was the intention to produce an 'occupancy map' for the Wairewa site also. However, due to the error in survey layout for the magnetic survey, the data points did not overlap and the map would not give a true representation of results. Map 2 shows the compilation of all results.

There are several locations identified as probable areas for unmarked graves (map 2), these areas have been highlighted on a summary map. The interesting areas show a dipolar response on the magnetic data, a mottled effect on the EM data and are represented by diffraction patterns on the radar profiles.

It must be noted that in the areas where there at many marked graves, the response from the content of the marked graves masks the response from the ground. However, we know these areas to already be occupied. Therefore, although data quality is poor in this area and results can not be interpreted with clarity in these areas, overall data is still useful.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this investigation was to determine if a range of geophysical techniques could be utilised to delineate the position of graves in possibly mildly conductive loess soils. It was therefore an aim to locate the positions of any unmarked graves, for the knowledge of the local runanga. A further aspect of the study was to examine the effect of cultural influences, such as fences and power lines, on geophysical results and to compare the results from the two sites, to examine how the differences affected the results.

Non-destructive, non-invasive geophysical methods were chosen for this investigation due to the sensitive nature of the study. It was deemed entirely appropriate to employ electromagnetic (EM), magnetic and ground-penetrating radar (GPR) techniques despite the tapu nature of the sites.

The study highlighted the importance of prior knowledge before commencing a geophysical survey. Maori tradition was researched and findings were applied in survey design. This contributed significantly to the success of the survey. The geomorphology of the site was inspected prior to commencement of the survey. It is thought the survey was successfully designed in order to obtain the maximum response from the target. This is an approach that should be adopted for all geophysical investigations.

It was hypothesised that the loess soils that mantle the hills of Banks Peninsula may be problematic in interpretation of geophysical results. However, the techniques selected were not affected by the possibly conductive nature of the soil. Despite this findings were still hindered by problems unique to the individual sites.

The local geology was an issue at Koukourarata. The EM results were significantly influenced by the near-surface presence of volcanic bedrock. The larger scale trend in conductivity masked any smaller anomalies that may have been present and only wide scale trends could be identified. Attempts to remove the background noise were of limited success. Fortunately, the magnetic and GPR surveys worked well.

Geomorphology of the site heavily influenced results. The small landslide showed clearly on the results of the EM survey. It was an appropriate decision not to proceed with the other techniques in this area.

At Koukourarata, cultural features, such as fences, power lines and marked graves, had little or no effect on the survey results. Influences from fences were contained to the western boundary of the survey and in the direct area surrounding the marked grave. The presence of the power lines had no visible influence on data quality.

Local geology and geomorphology of the site did not degrade the results obtained from the survey at Wairewa. However, due to the active nature of the site there were many cultural features that showed clearly in the data sets. The presence of fences, trees and marked graves influenced the results. In these areas the response from such items may have masked smaller anomalies.

It is concluded that to achieve reliable geophysical results a combination of techniques should be employed. The three techniques used in this investigation were complimentary. The EM is a quick and easy method; therefore, it is useful for conducting a reconnaissance survey.

However, it proved to be very sensitive to the bedrock geology and the presence of cultural items. The magnetometer/gradiometer technique was useful and generally confirmed the somewhat dubious findings of the EM survey. Anomalies generally appeared as dipolar features on the magnetic plots. The combination of these techniques allowed the survey area to be narrowed down to areas of interest. The GPR investigation complimented the other techniques as it provides immense detail. It was found that lower frequency GPR systems are more appropriate in this application.

In general the surveys at both sites were successful and yielded some interesting results. The marked graves could be used as a control and these were identified in most cases from a combination of the three techniques.

It is felt that a boundary can be placed with relative confidence around the urupa at Koukourarata. The areas showing significant disturbance have been highlighted at the Wairewa site also. Summary maps have been provided showing the possible to probable locations of the unmarked graves. Unfortunately, results from the lower survey area at Koukourarata were inconclusive. However, it is thought unlikely that graves exist in this area.

Without physical constraints it is impossible to the entirely rely upon geophysical results of any kind. Due to the sensitive nature of this site, excavations are impossible. Therefore, one can not think of a more appropriate method of determining the approximate location of the graves so as they can be treated with appropriate respect.

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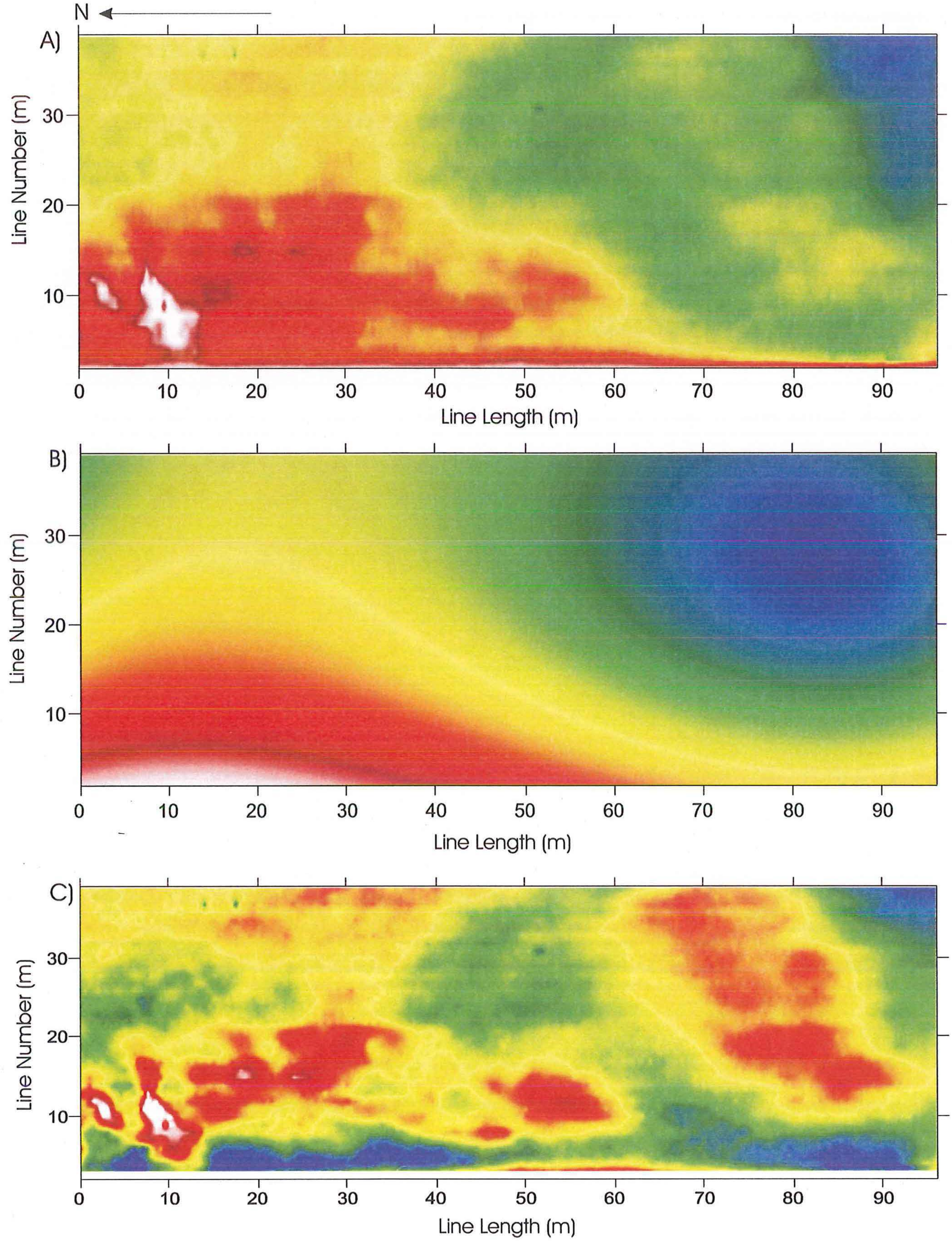
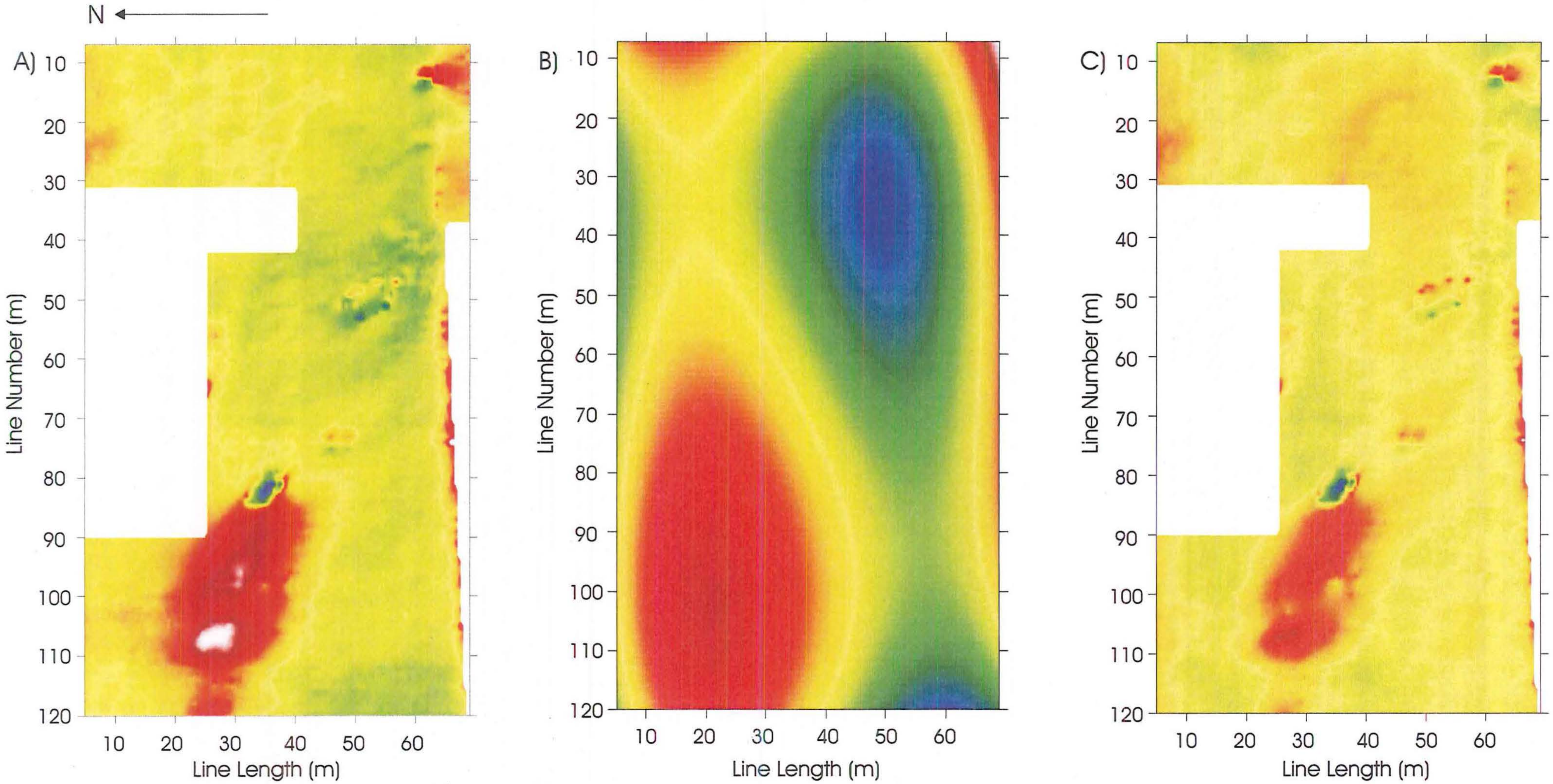
APPENDIX I

ELECTROMAGNETIC SURVEY RESULTS
Koukourarata



A) Raw EM results. B) Data with cubic polynomial regression surface applied to smooth results. C) Residual results (A- B = C)

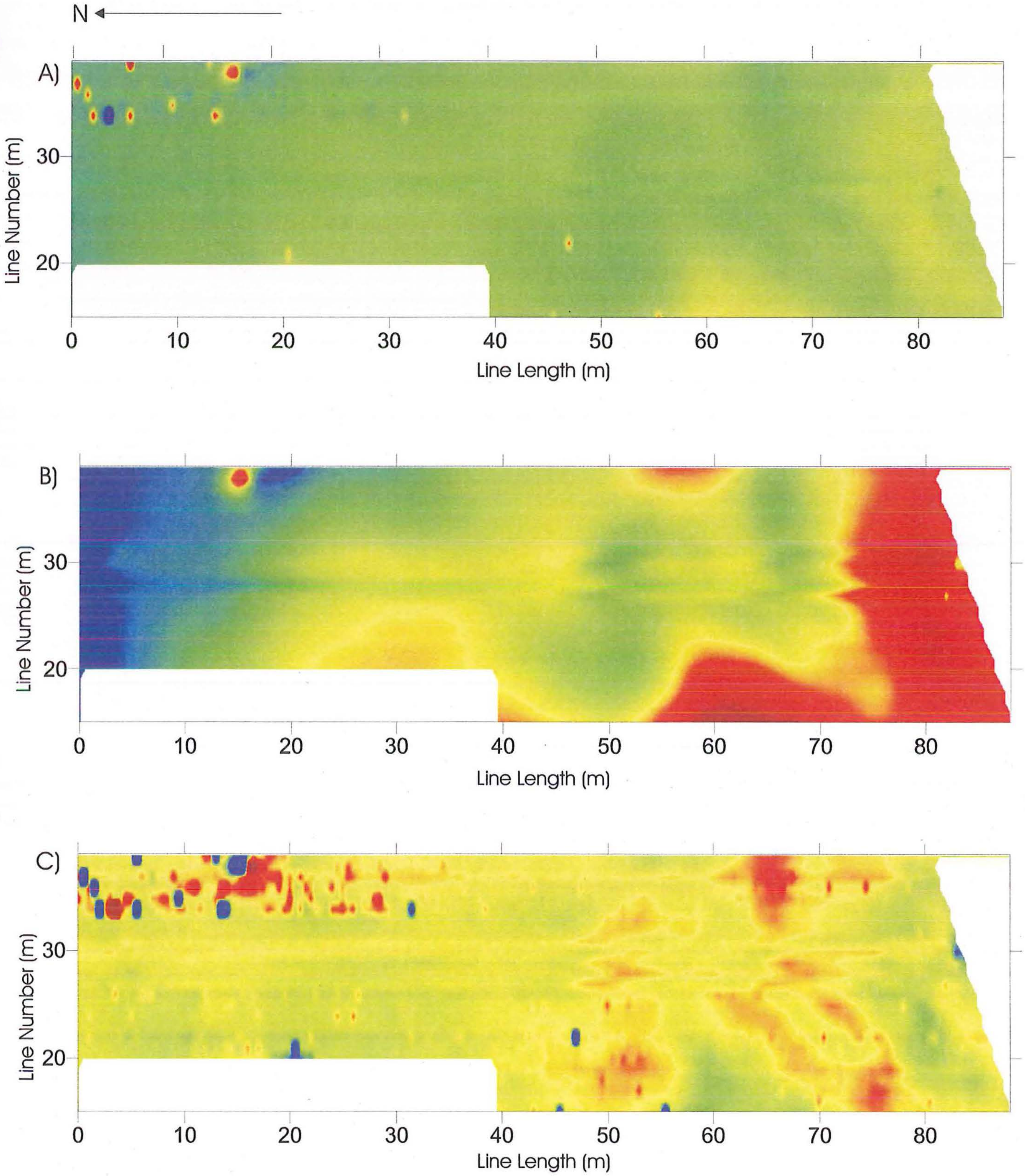
ELECTROMAGNETIC RESULTS
Wairewa



A) Raw EM results. B) Data with cubic polynomial regression surface applied to smooth results. C) Residual results (A- B = C)

APPENDIX II

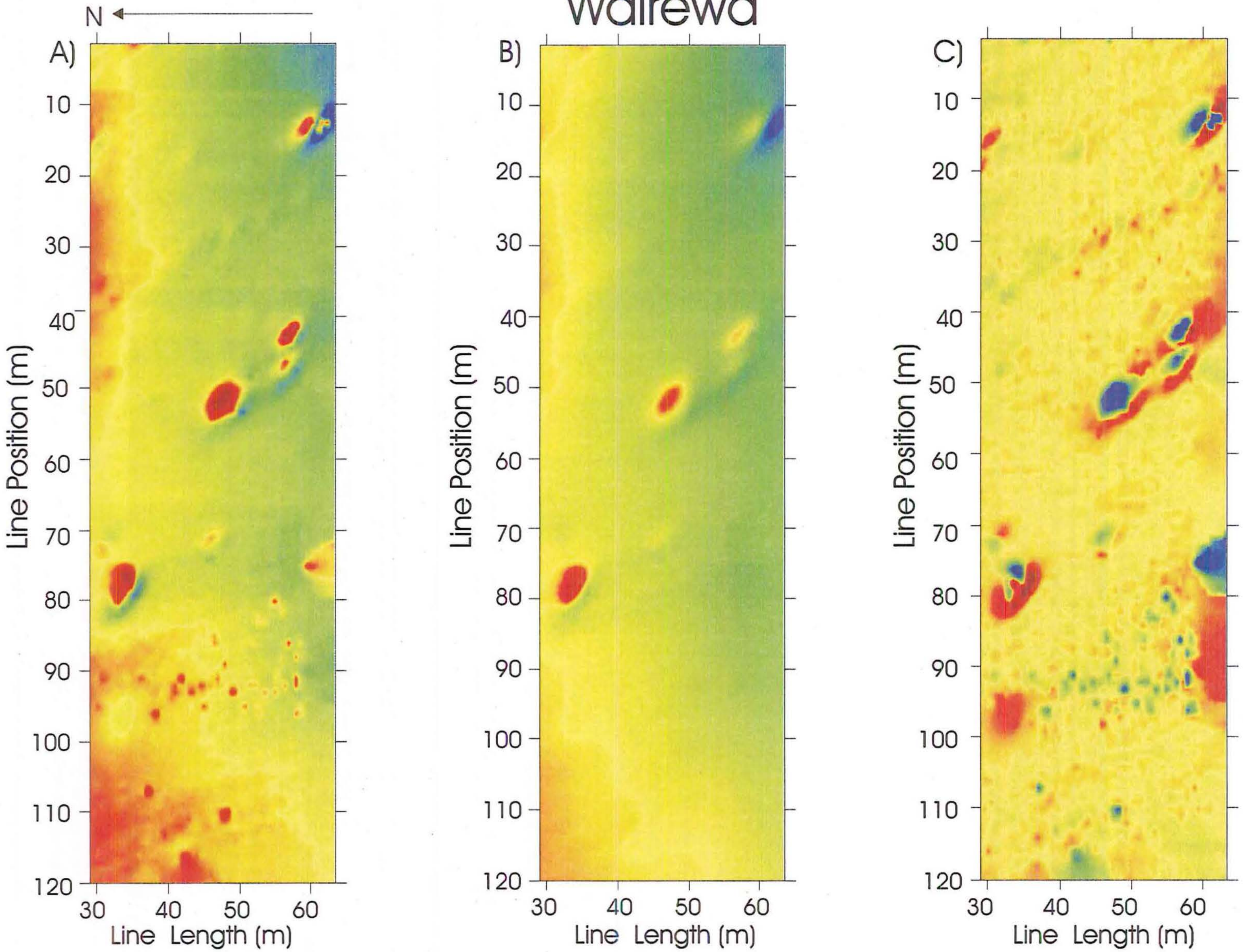
MAGNETIC SURVEY RESULTS
Koukourarata



A) Top sensor readings B) Bottom sensor readings
C) Magnetic gradient

MAGNETIC SURVEY RESULTS

Wairewa



A) Top sensor readings B) Bottom sensor readings C) Magnetic gradient

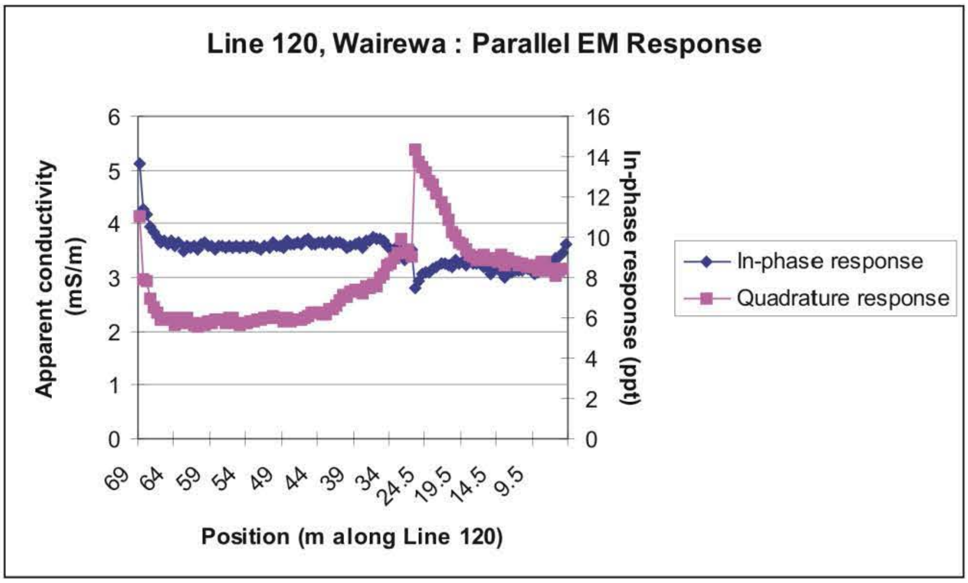
APPENDIX III
EM DATA QUALITY CHARTS

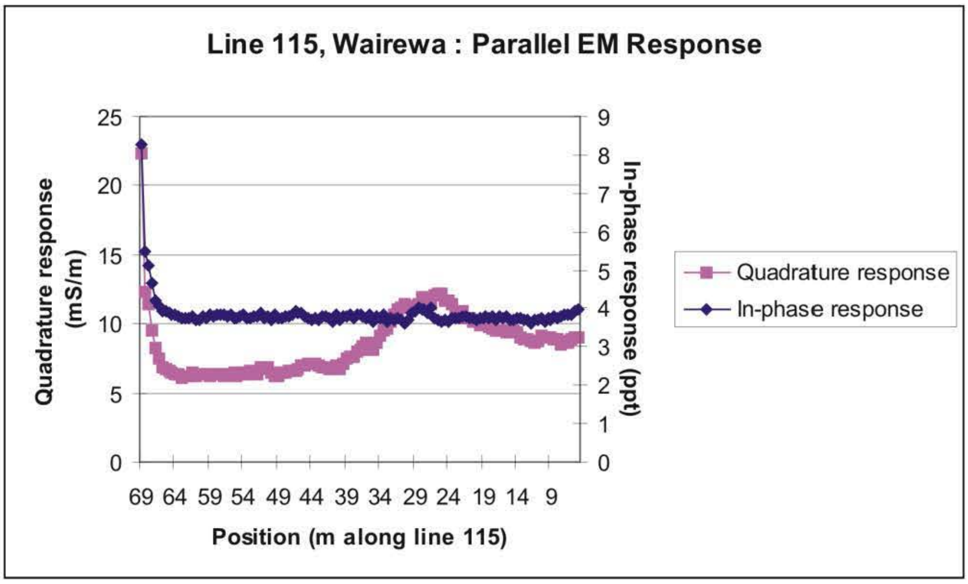
WAIREWA

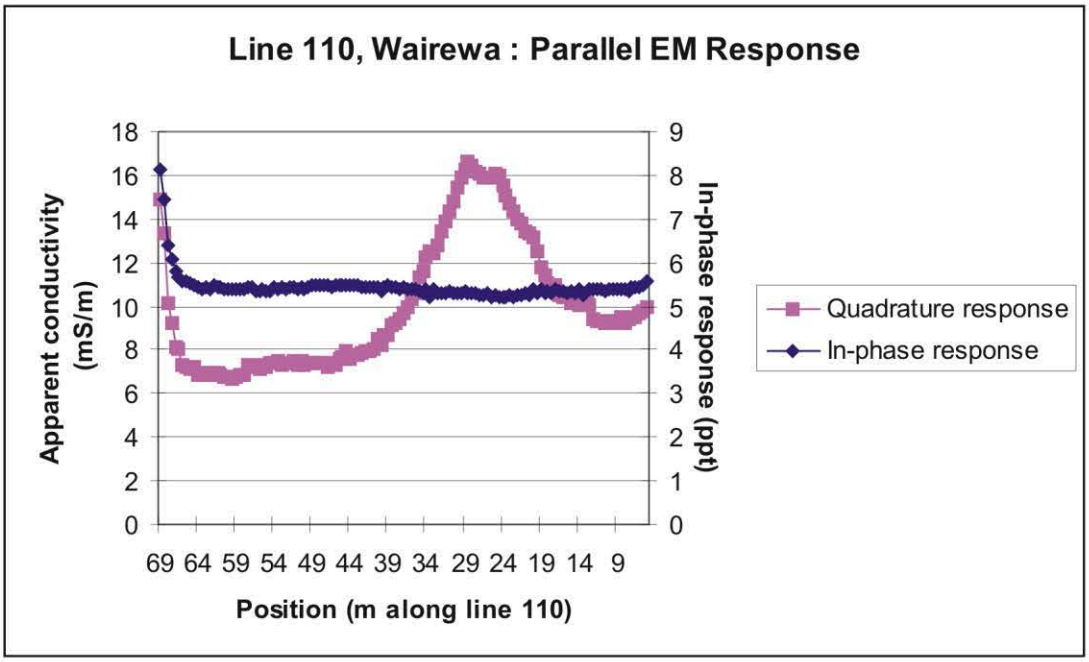
APPENDIX III

DATA QUALITY OF ELECTROMAGNETIC SURVEY

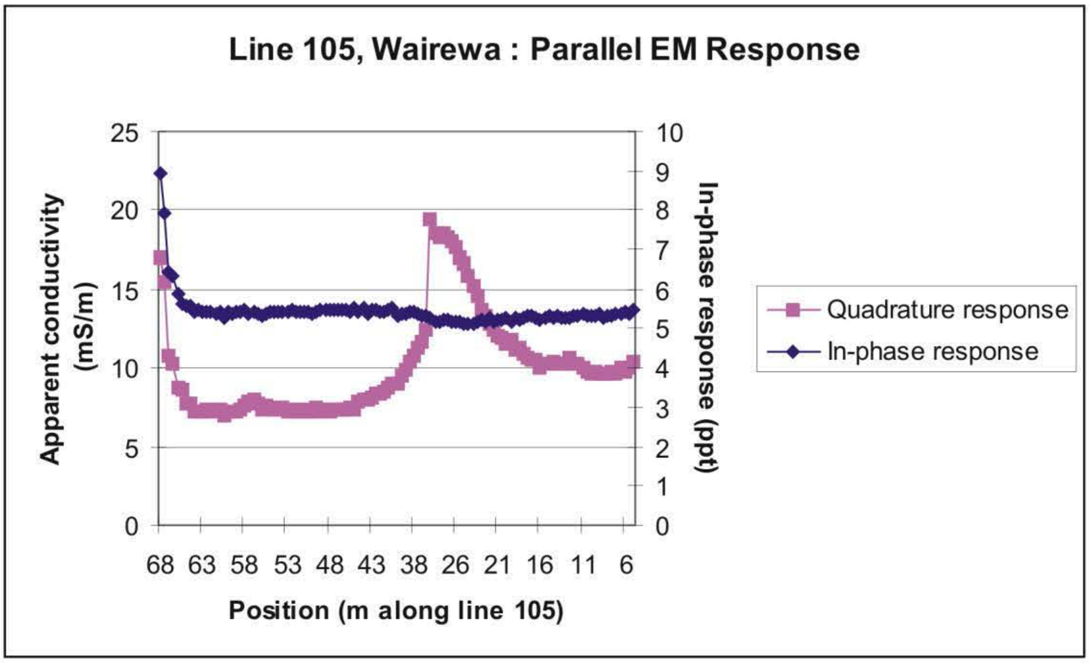
Wairewa



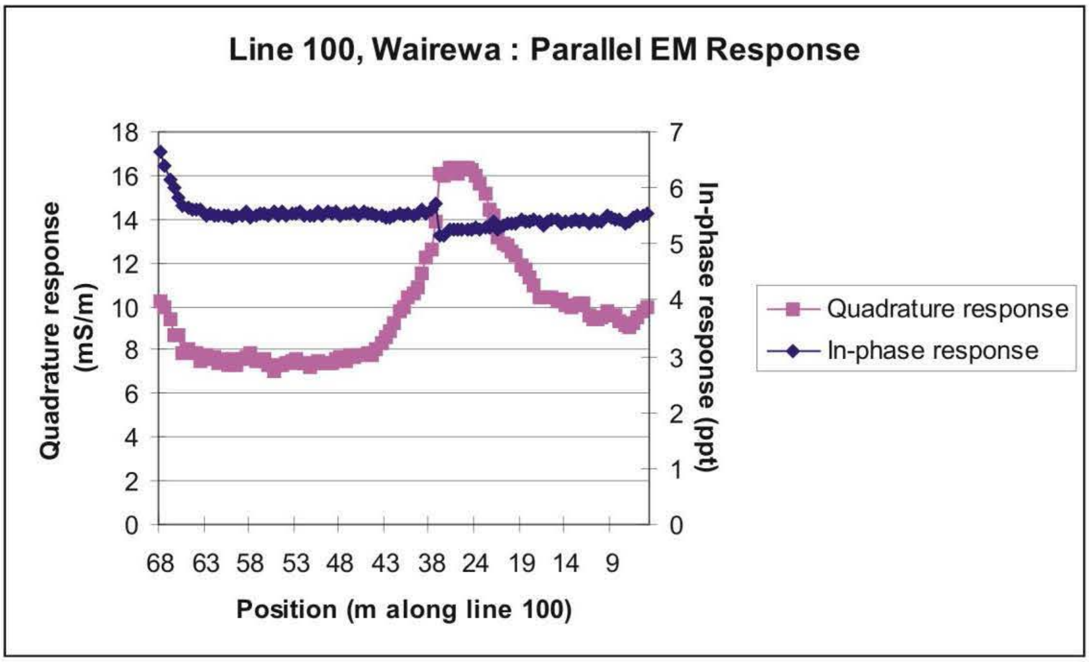


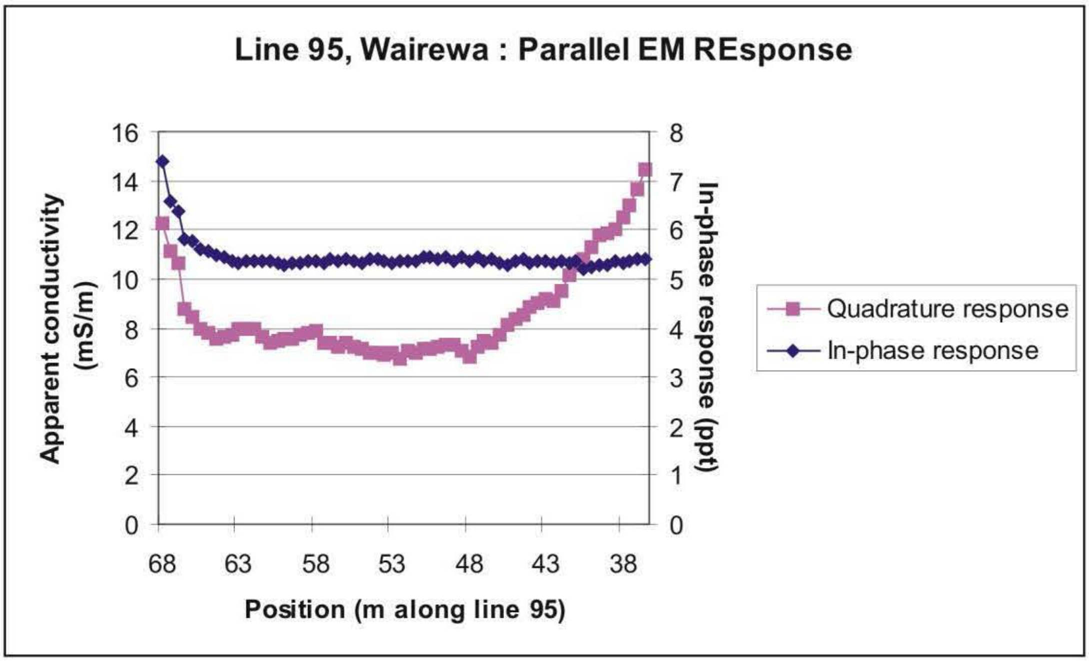


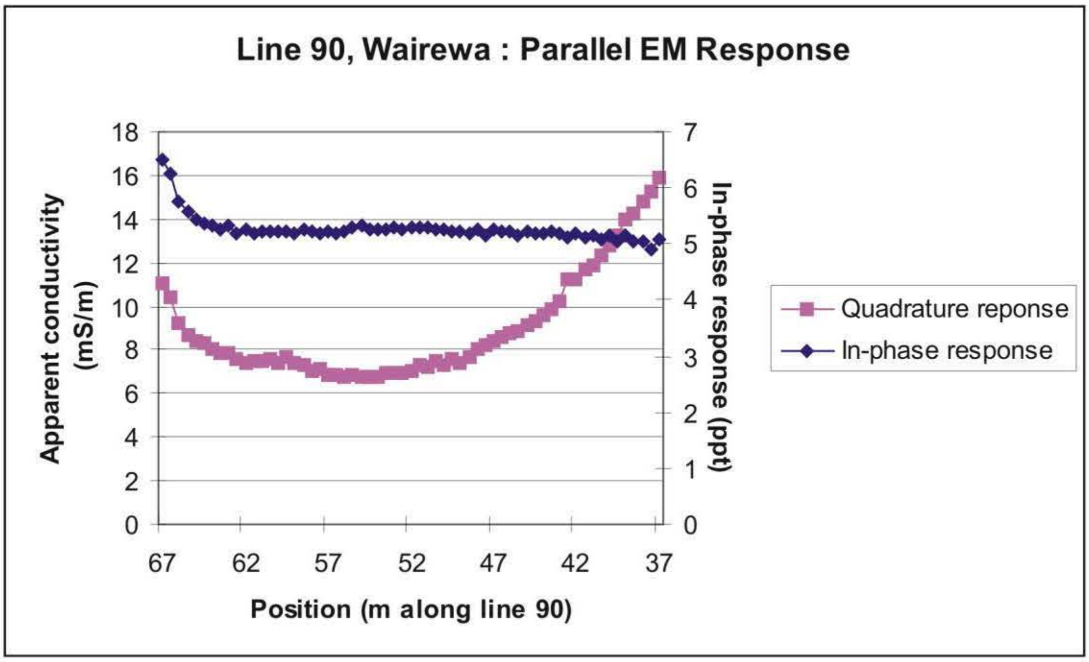
Line 110, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
18
16
14
12
10
8
6
4
2
0
9
8
7
6
5
4
3
2
1
0
In-phase response (ppt)
69 64 59 54 49 44 39 34 29 24 19 14 9
Position (m along line 110)
Quadrature response
In-phase response



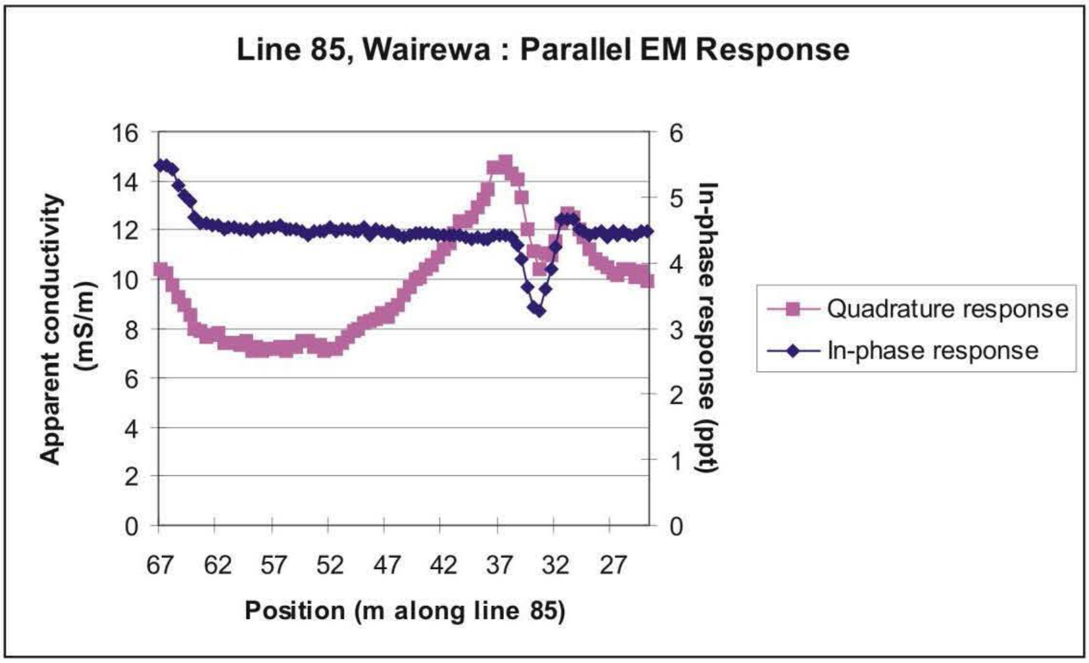
Line 105, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
25
20
15
10
5
0
10
9
8
7
6
5
4
3
2
1
0
In-phase response (ppt)
68 63 58 53 48 43 38 26 21 16 11 6
Position (m along line 105)
Quadrature response
In-phase response


Line 100, Wairewa : Parallel EM Response
Quadrature response (mS/m)
In-phase response (ppt)
Position (m along line 100)
68 63 58 53 48 43 38 24 19 14 9
Quadrature response
In-phase response

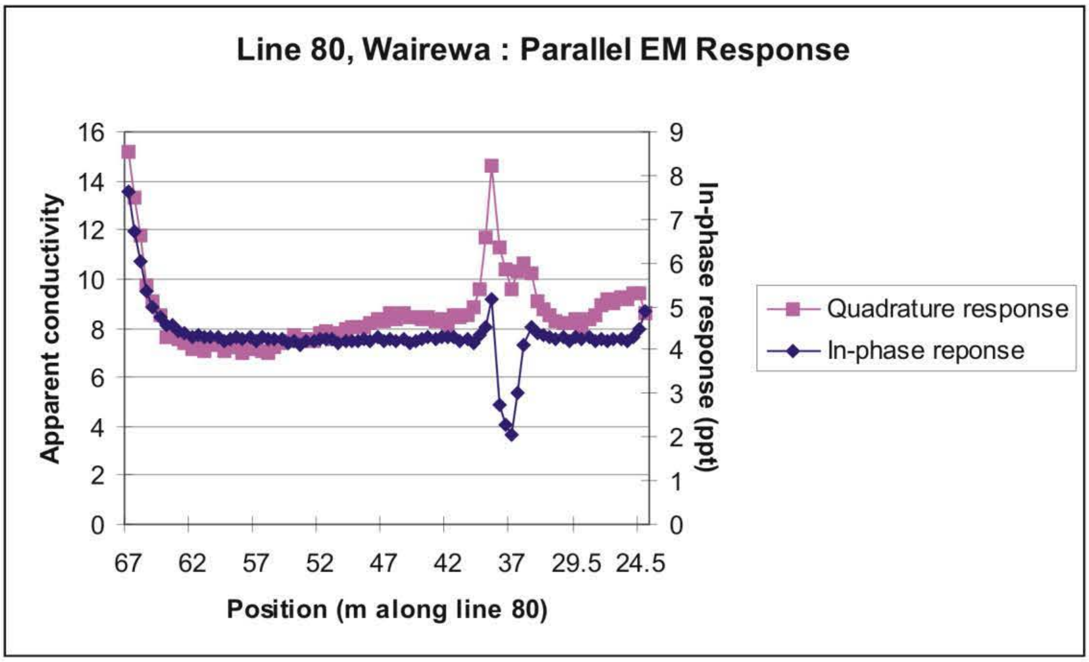

Line 95, Wairewa : Parallel EM REsponse
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 95)
68 63 58 53 48 43 38
Quadrature response
In-phase response

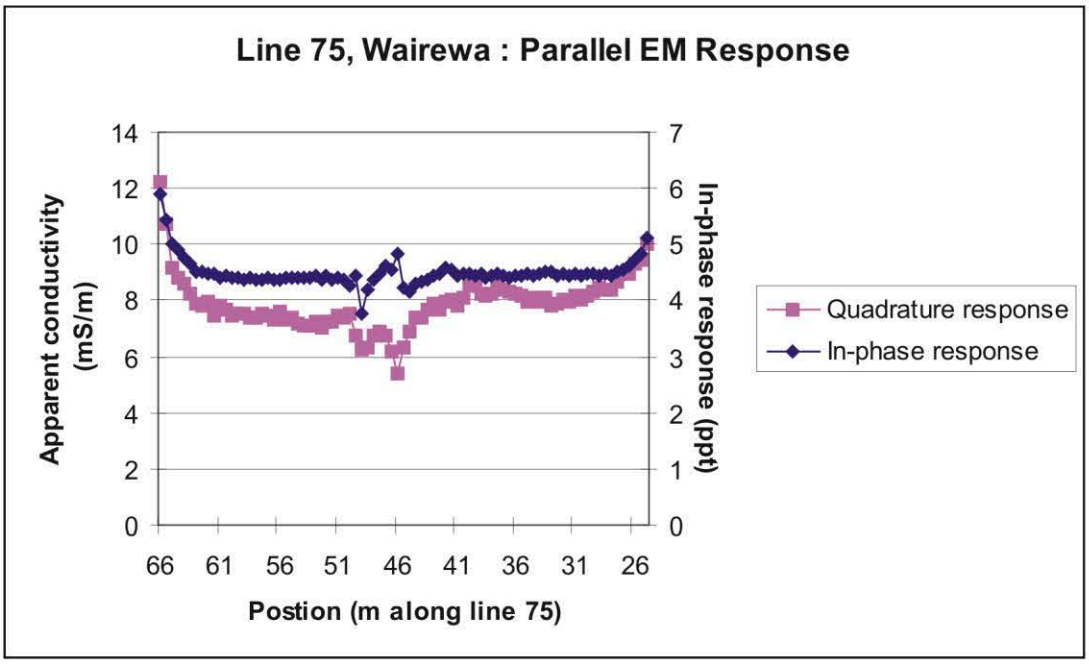


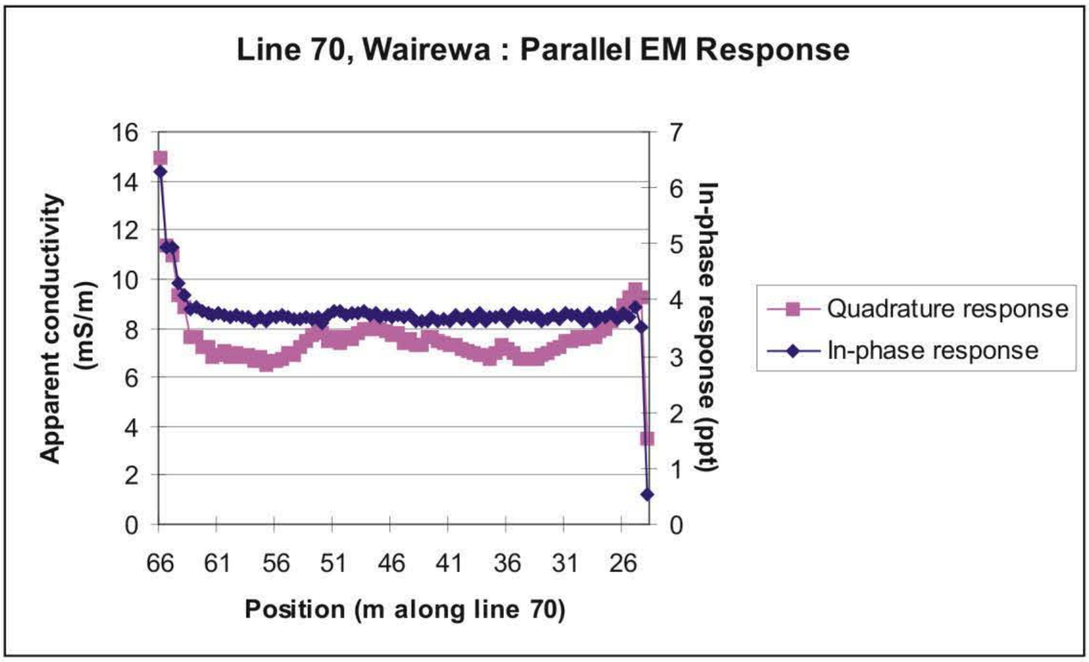
Line 90, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 90)
Quadrature reponse
In-phase response

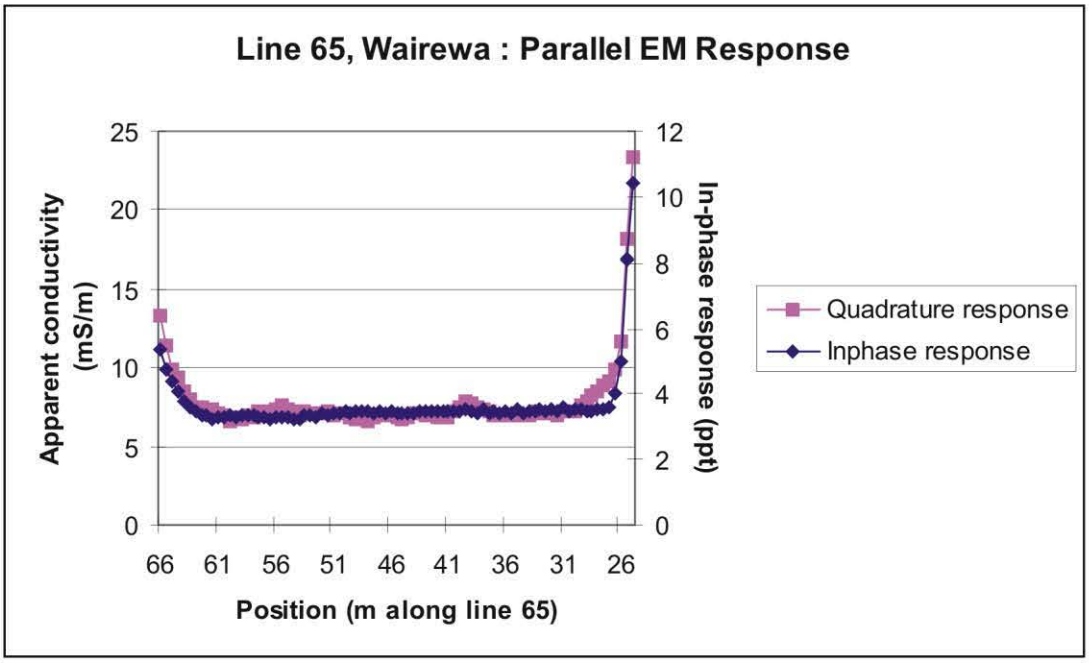


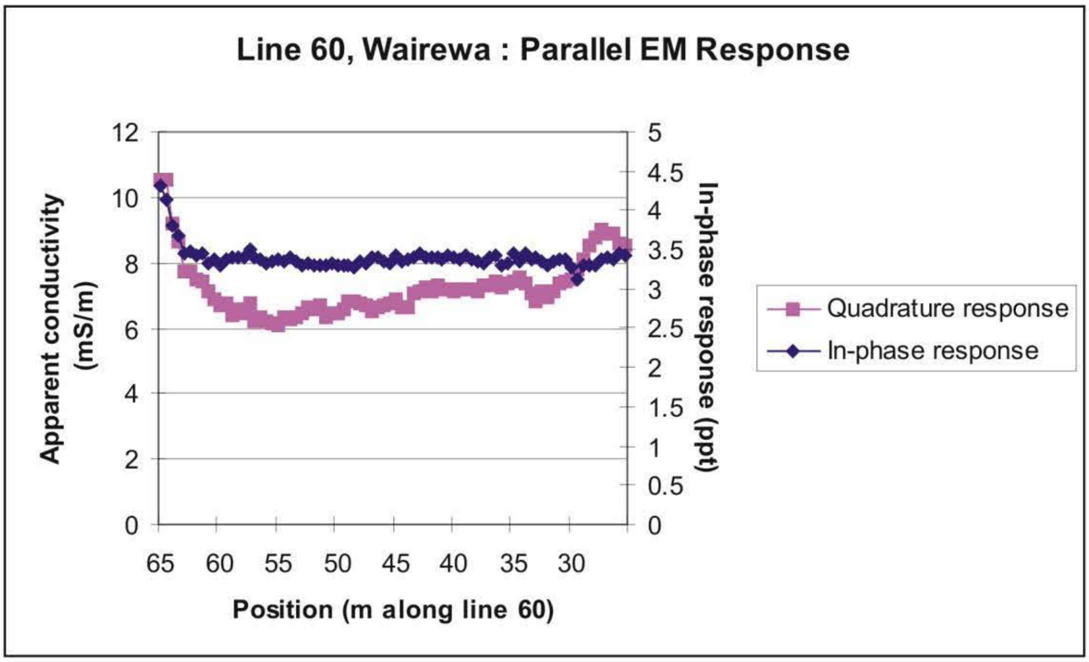
Line 85, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 85)
Quadrature response
In-phase response


Line 80, Wairewa : Parallel EM Response
Apparent conductivity
In-phase response (ppt)
16
14
12
10
8
6
4
2
0
9
8
7
6
5
4
3
2
1
0
67
62
57
52
47
42
37
29.5
24.5
Position (m along line 80)
Quadrature response
In-phase reponse

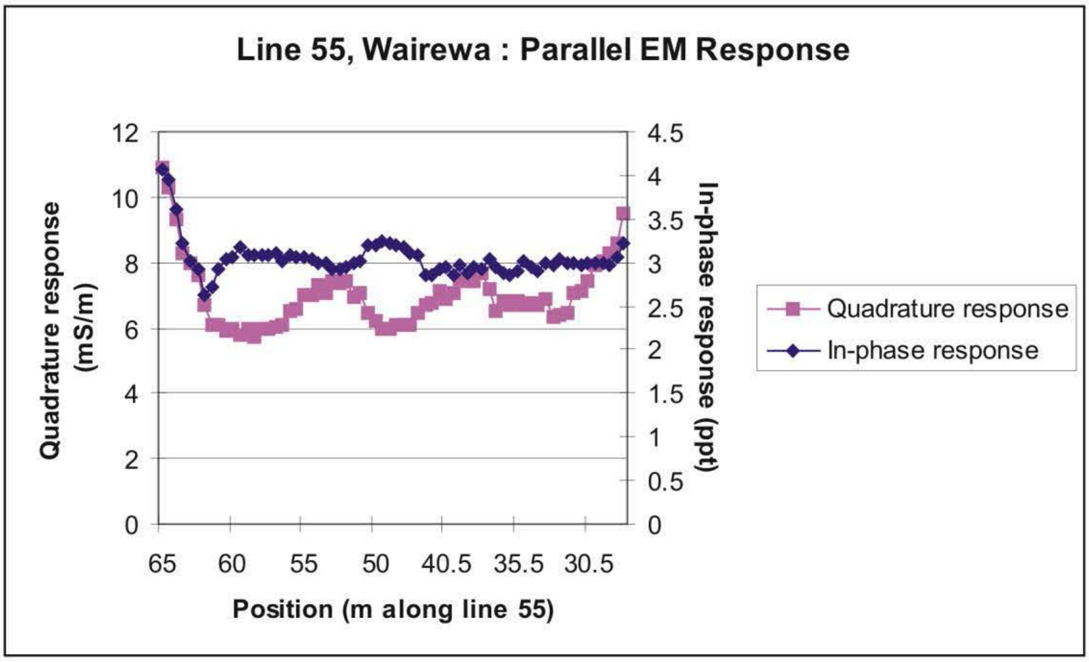

Line 75, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
14
12
10
8
6
4
2
0
7
6
5
4
3
2
1
0
66
61
56
51
46
41
36
31
26
Postion (m along line 75)
Quadrature response
In-phase response


Line 70, Wairewa : Parallel EM Response
16
14
12
10
8
6
4
2
0
7
6
5
4
3
2
1
0
Apparent conductivity (mS/m)
In-phase response (ppt)
66
61
56
51
46
41
36
31
26
Position (m along line 70)
Quadrature response
In-phase response

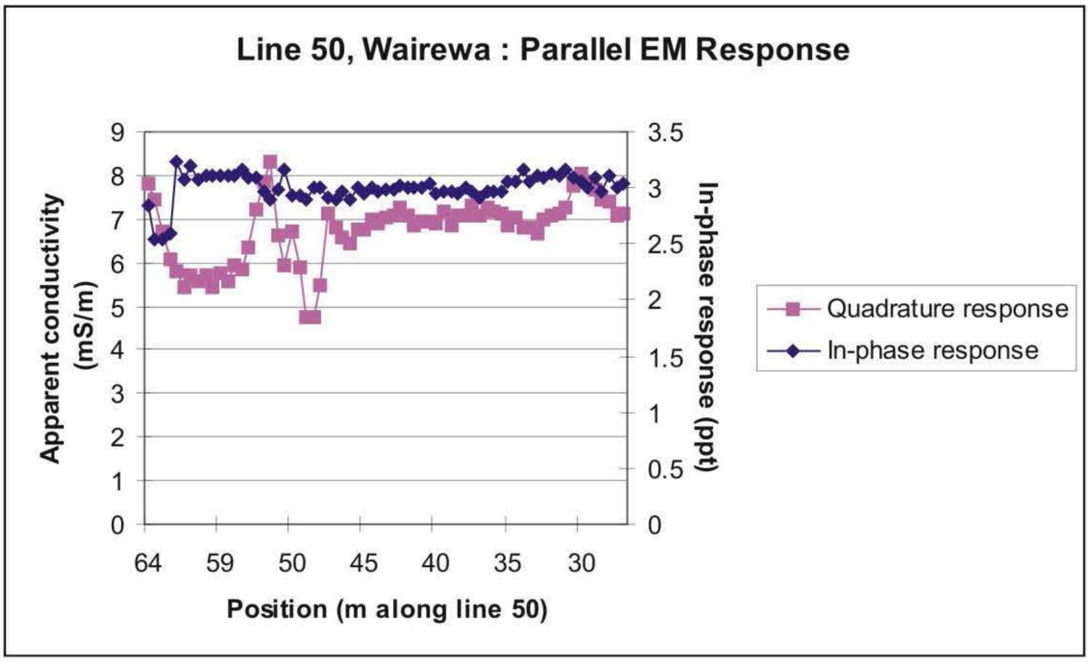

Line 65, Wairewa : Parallel EM Response
25
20
15
10
5
0
12
10
8
6
4
2
0
Apparent conductivity (mS/m)
In-phase response (ppt)
66
61
56
51
46
41
36
31
26
Position (m along line 65)
Quadrature response
Inphase response

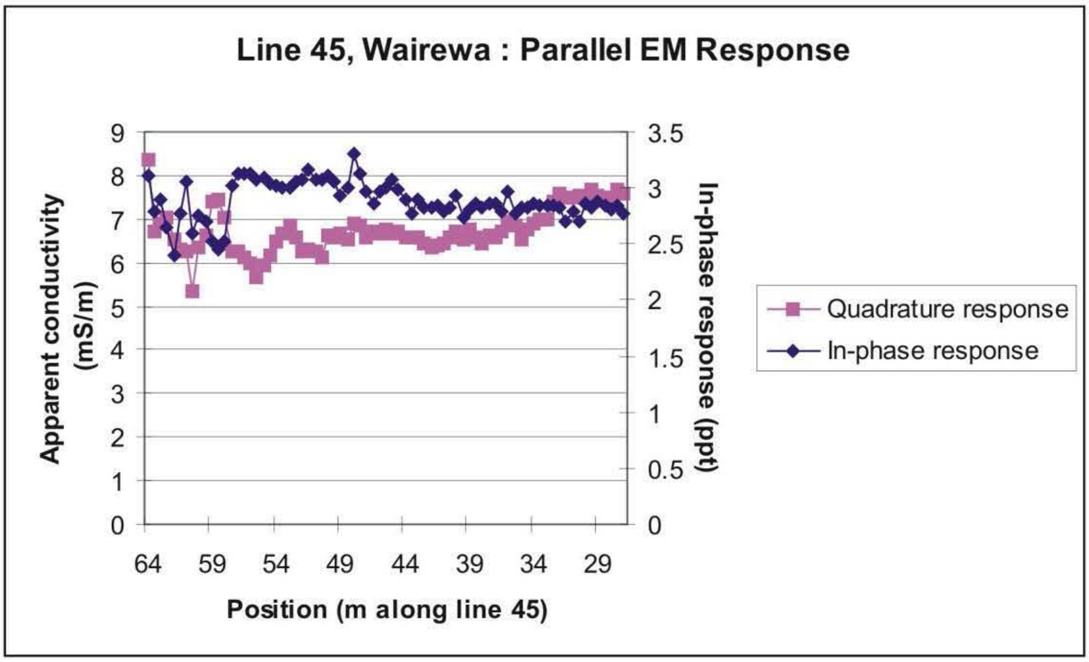


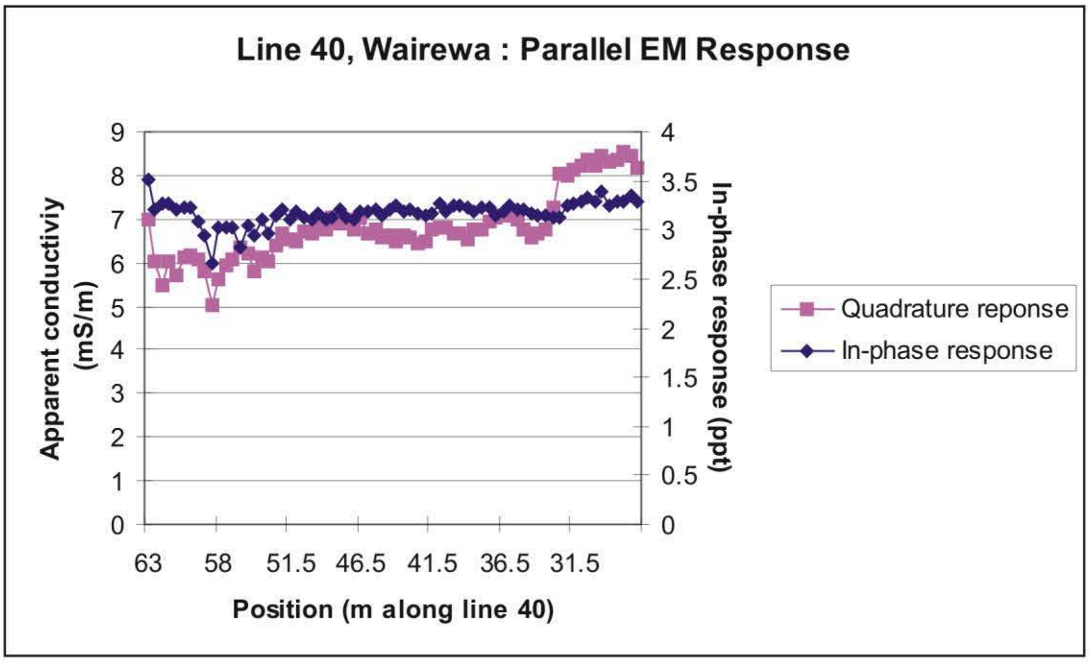
Line 60, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 60)
Quadrature response
In-phase response

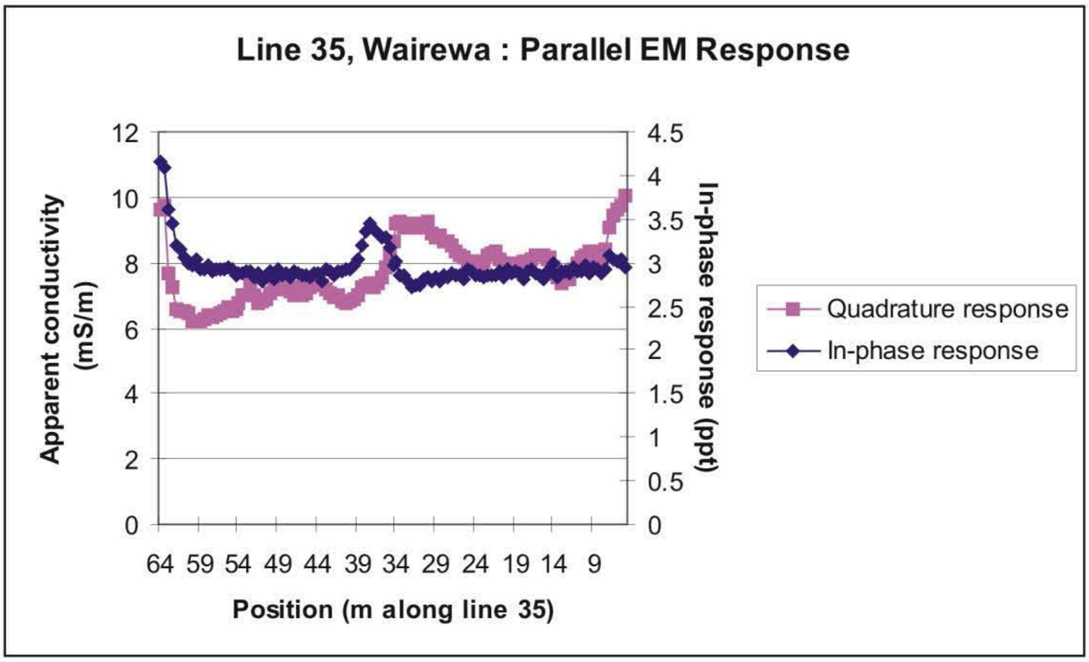


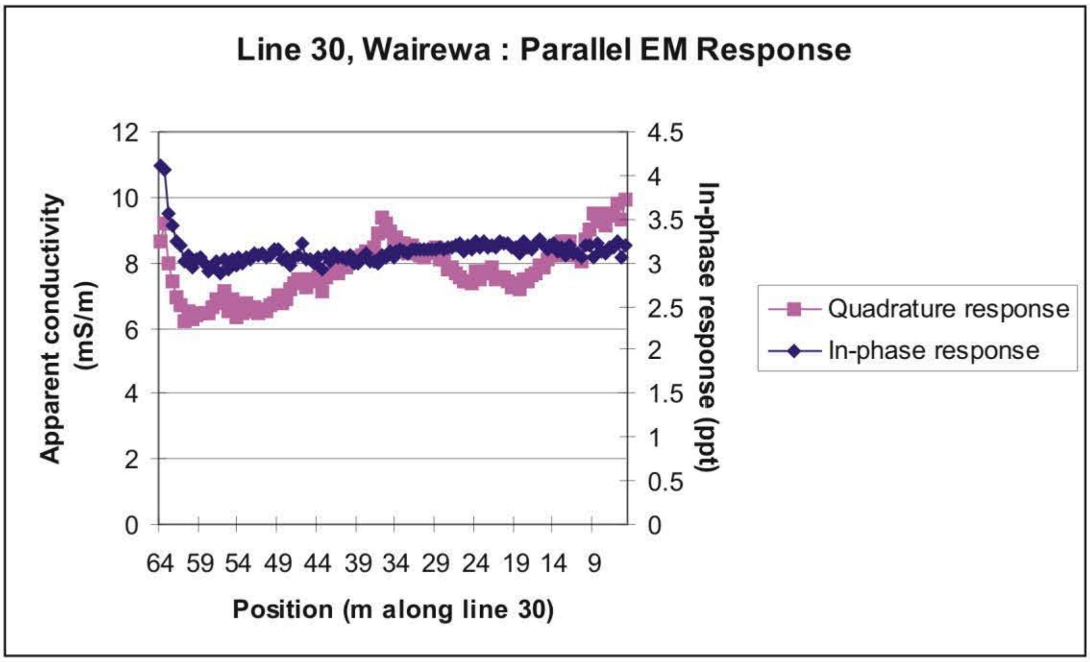
Line 55, Wairewa : Parallel EM Response
Quadrature response (mS/m)
In-phase response (ppt)
Position (m along line 55)
Quadrature response
In-phase response

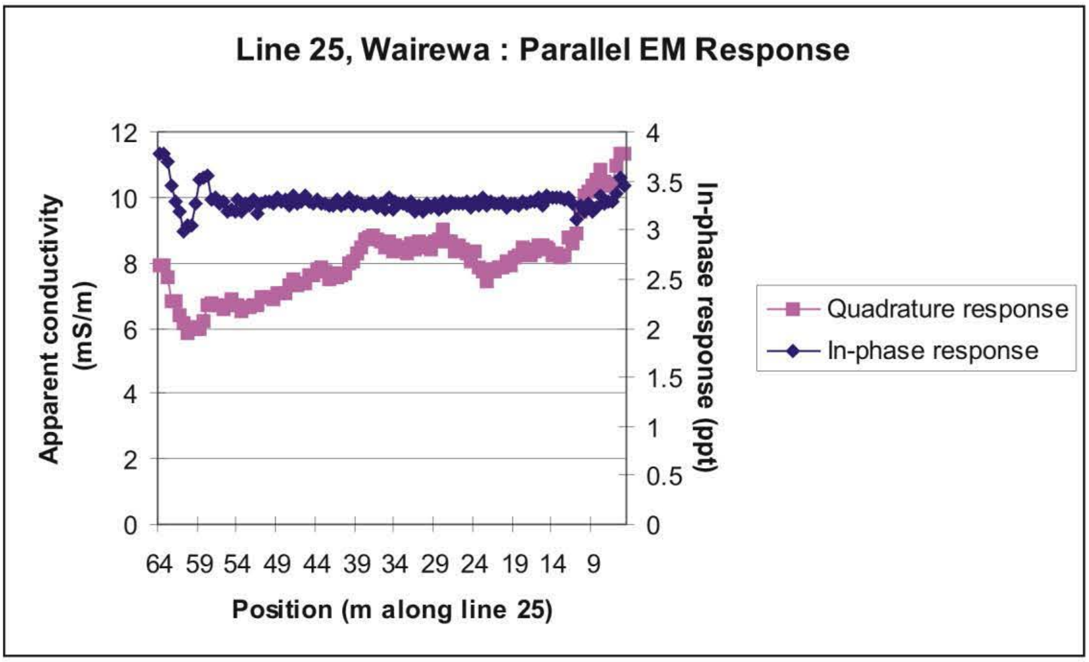

Line 50, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 50)
Quadrature response
In-phase response
9
8
7
6
5
4
3
2
1
0
3.5
3
2.5
2
1.5
1
0.5
0
64
59
50
45
40
35
30

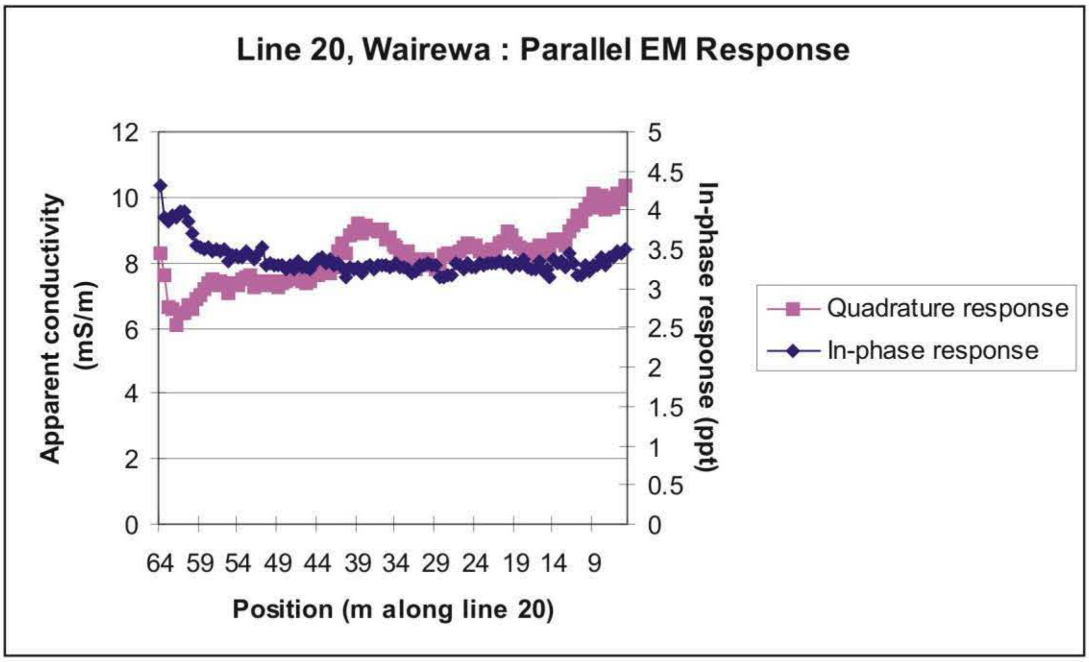

Line 45, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 45)
Quadrature response
In-phase response
9
8
7
6
5
4
3
2
1
0
3.5
3
2.5
2
1.5
1
0.5
0
64
59
54
49
44
39
34
29


Line 40, Wairewa : Parallel EM Response
Apparent conductiviy (mS/m)
9
8
7
6
5
4
3
2
1
0
In-phase response (ppt)
4
3.5
3
2.5
2
1.5
1
0.5
0
63
58
51.5
46.5
41.5
36.5
31.5
Position (m along line 40)
Quadrature reponse
In-phase response

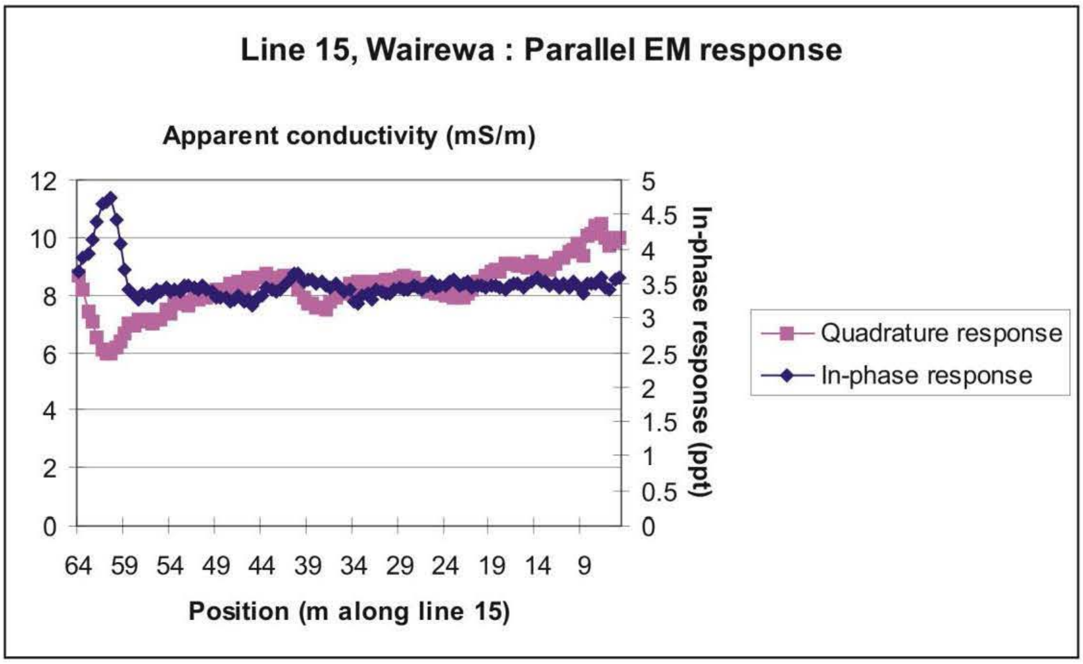

Line 35, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
12
10
8
6
4
2
0
In-phase response (ppt)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
64 59 54 49 44 39 34 29 24 19 14 9
Position (m along line 35)
Quadrature response
In-phase response


Line 30, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 30)
Quadrature response
In-phase response

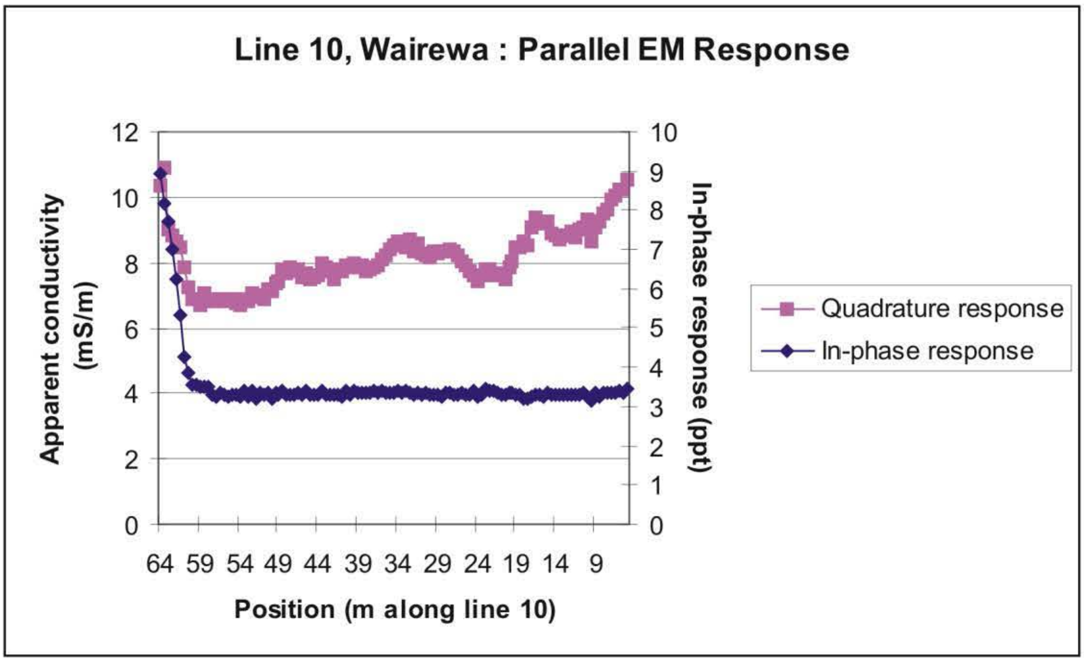

Line 25, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 25)
Quadrature response
In-phase response



Line 20, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 20)
Quadrature response
In-phase response
0
2
4
6
8
10
12
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
64 59 54 49 44 39 34 29 24 19 14 9

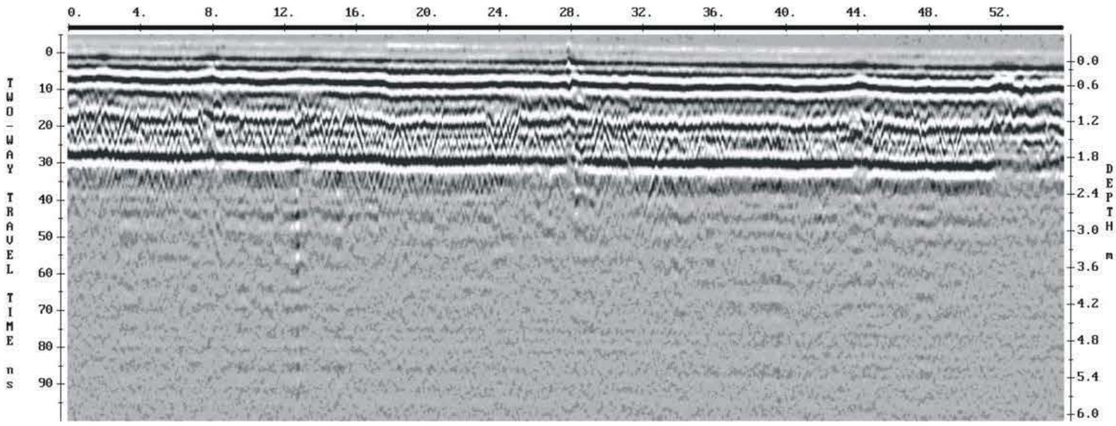


Line 15, Wairewa : Parallel EM response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 15)
Quadrature response
In-phase response
0
2
4
6
8
10
12
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
64 59 54 49 44 39 34 29 24 19 14 9

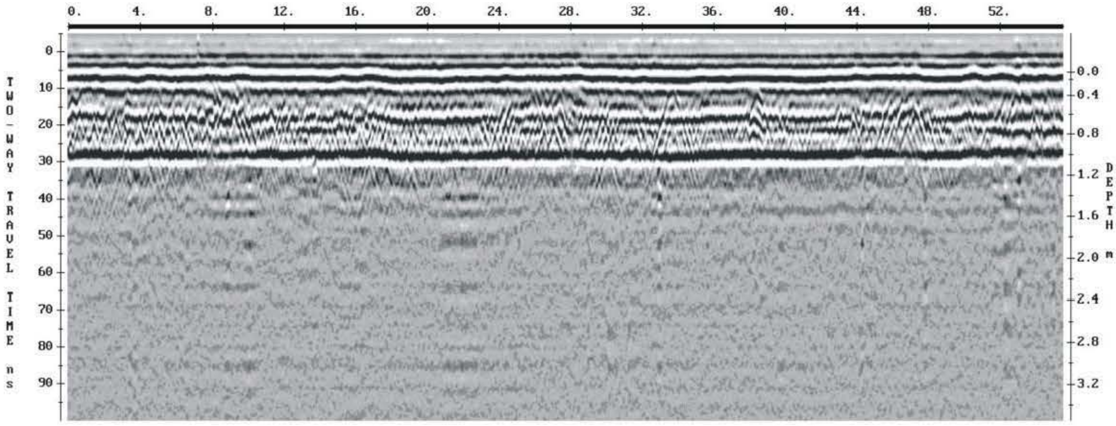

Line 10, Wairewa : Parallel EM Response
Apparent conductivity (mS/m)
In-phase response (ppt)
Position (m along line 10)
Quadrature response
In-phase response
12
10
8
6
4
2
0
9
7
5
3
1
64 59 54 49 44 39 34 29 24 19 14 9

APPENDIX IV
GPR SURVEYS
(part 1 of 3)

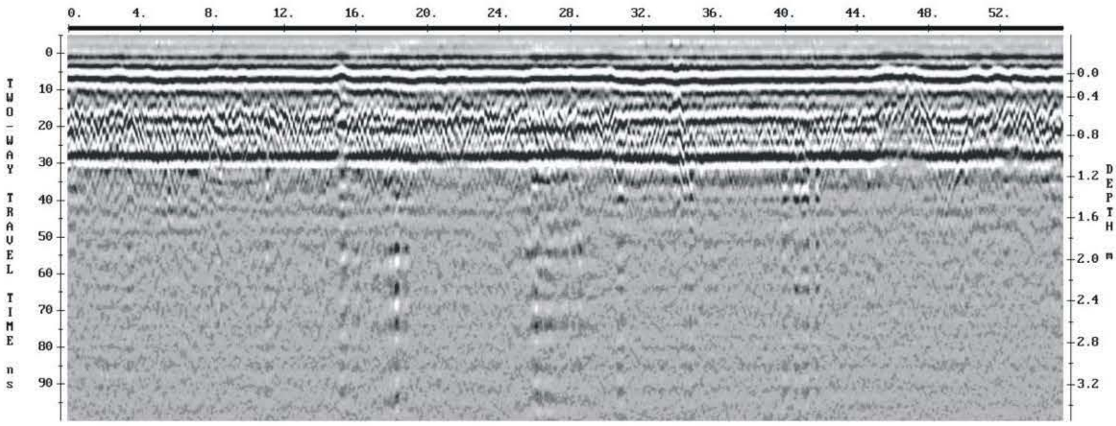
KOUKOURARATA
Upper survey grid
225 MHz Frequency



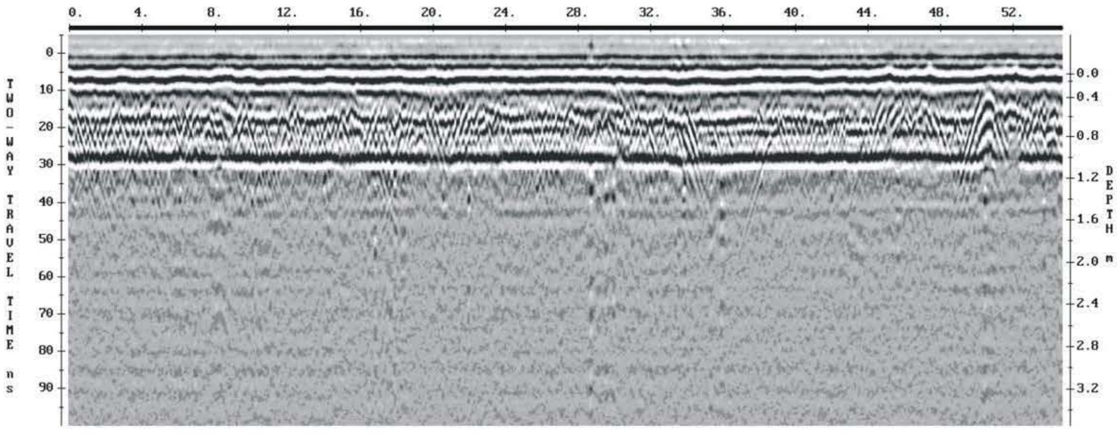
Line 1



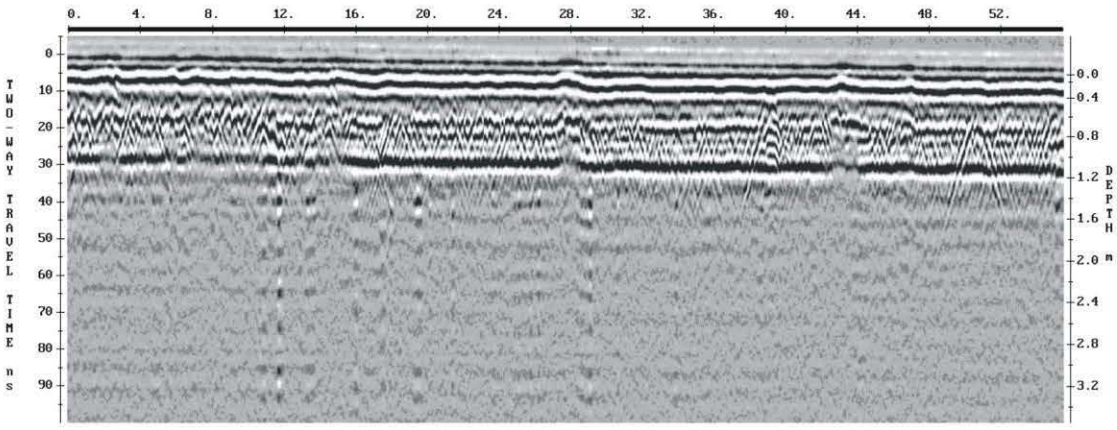
Line 2



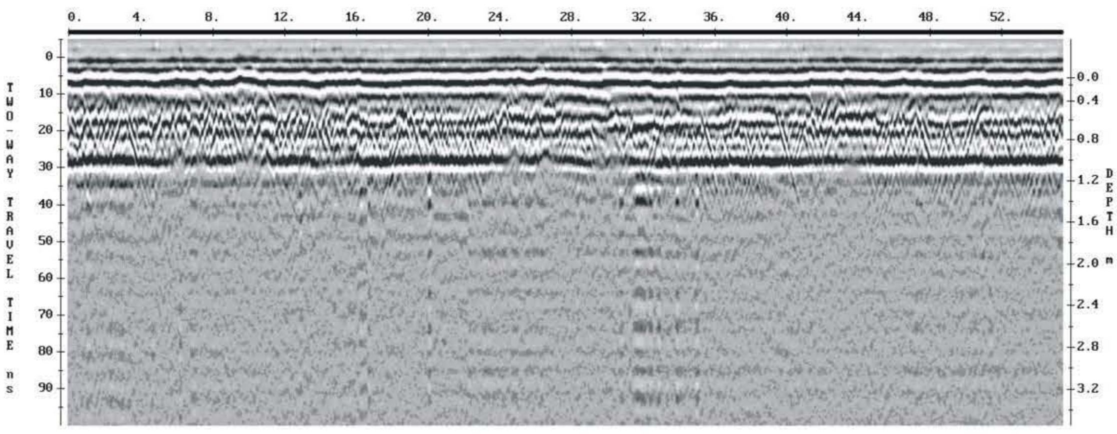
Line 3



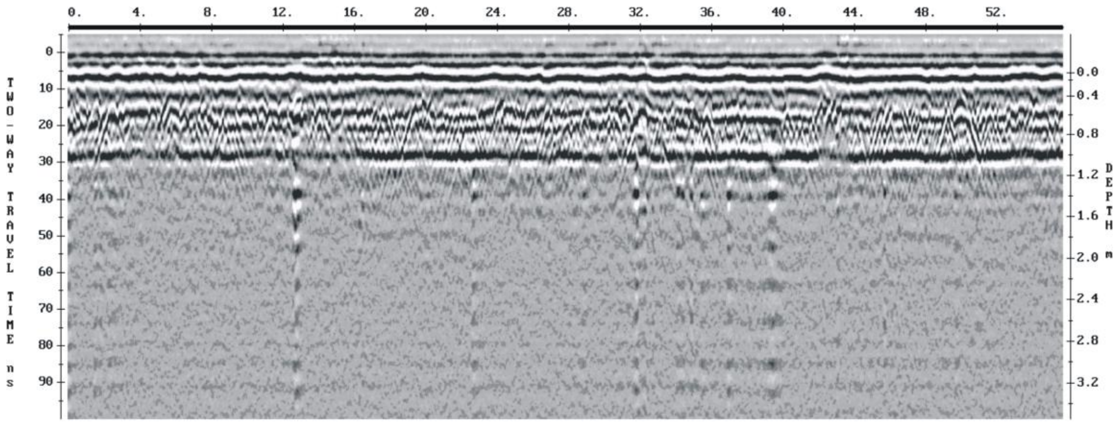
Line 4



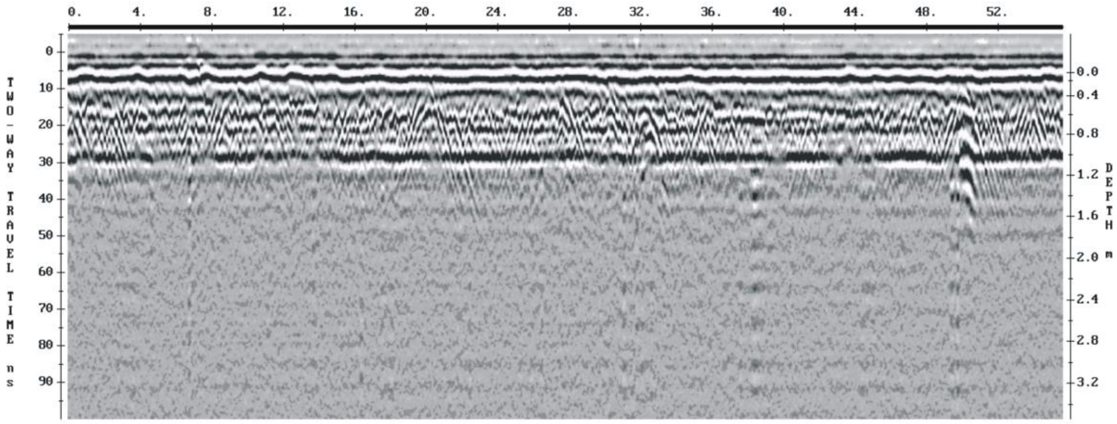
Line 5



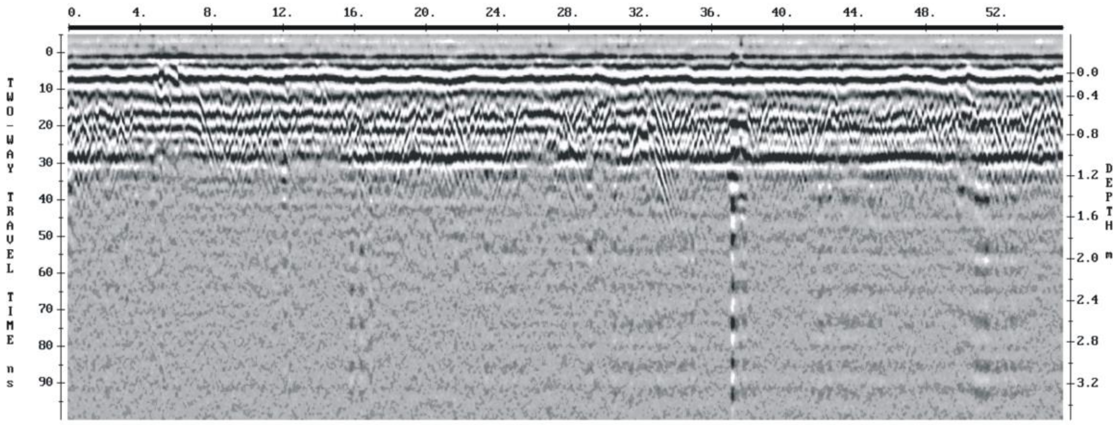
Line 6



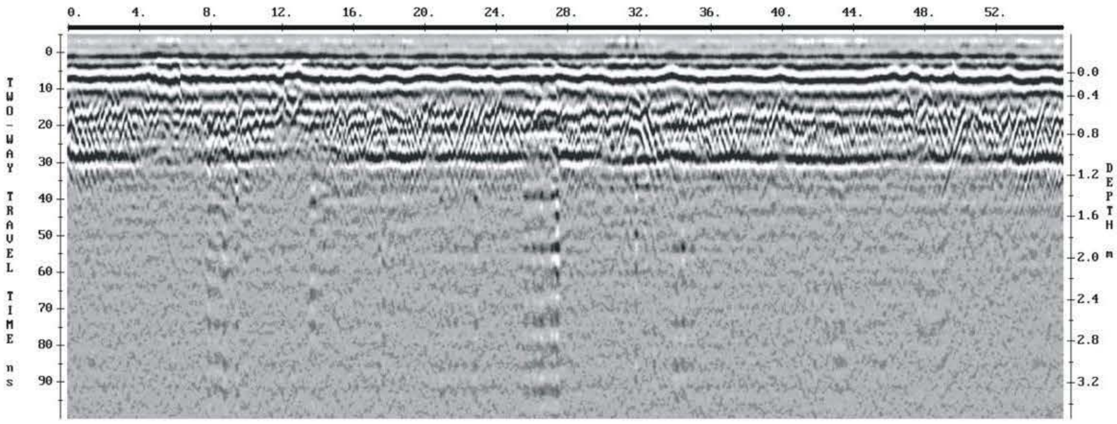
Line 7



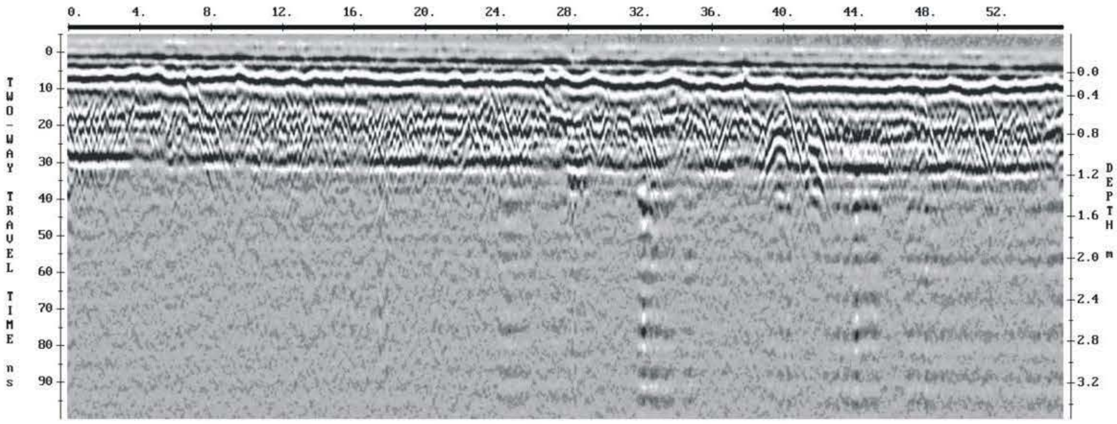
Line 8



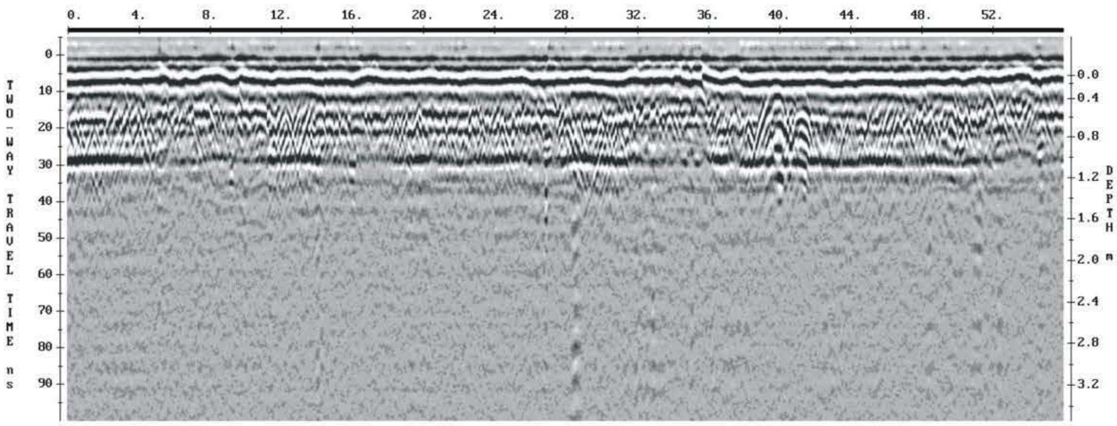
Line 9



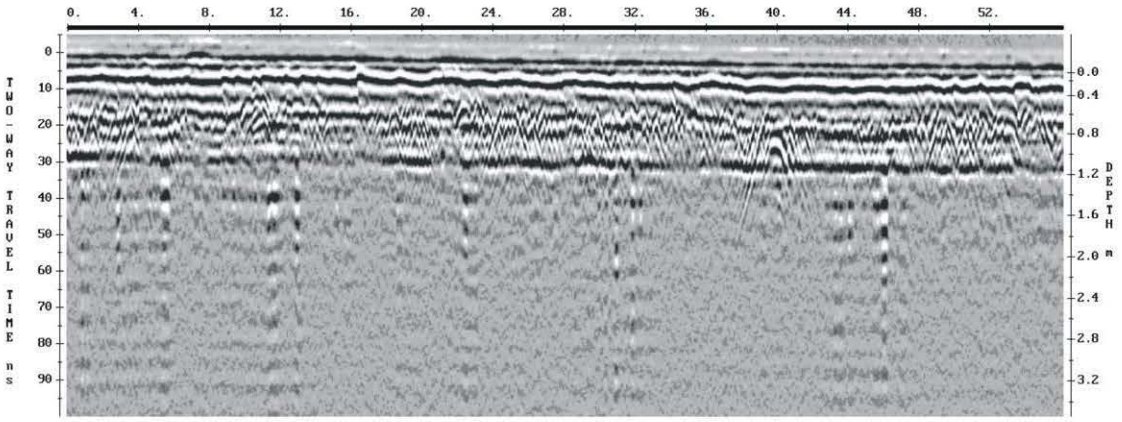
Line 10



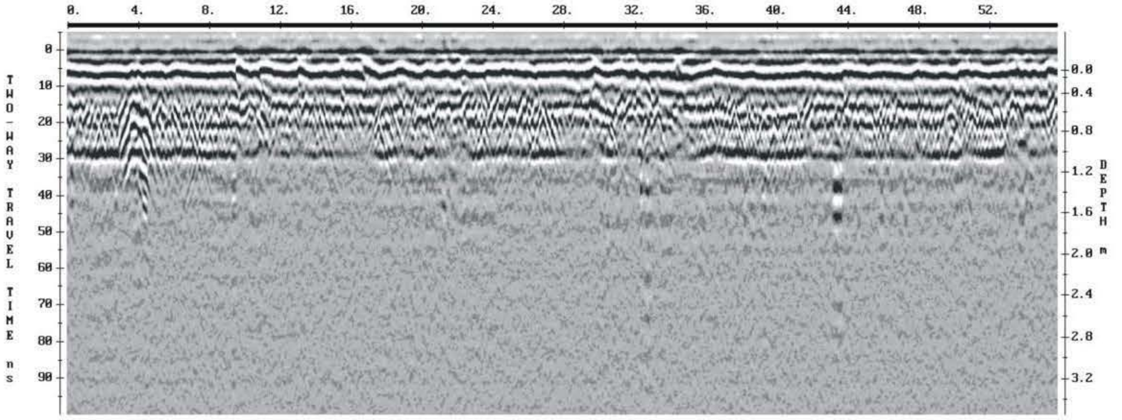
Line 11



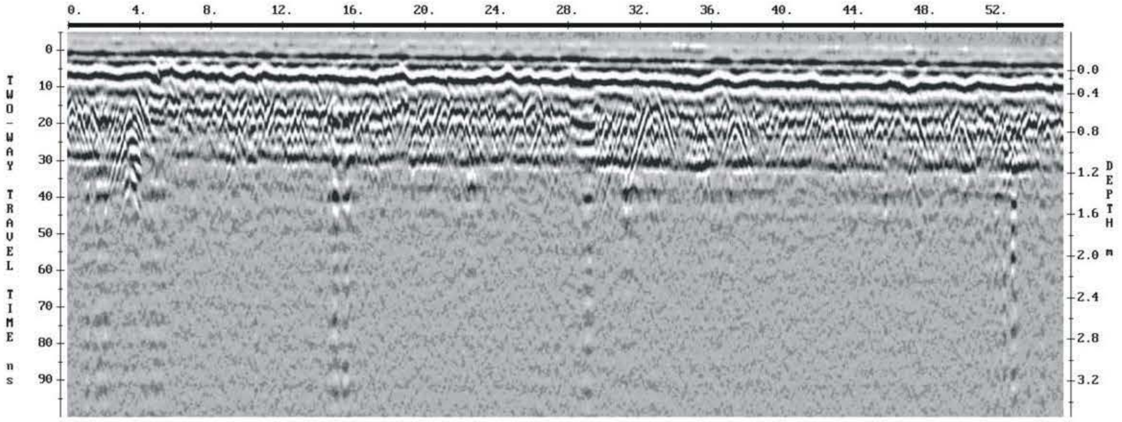
Line 12



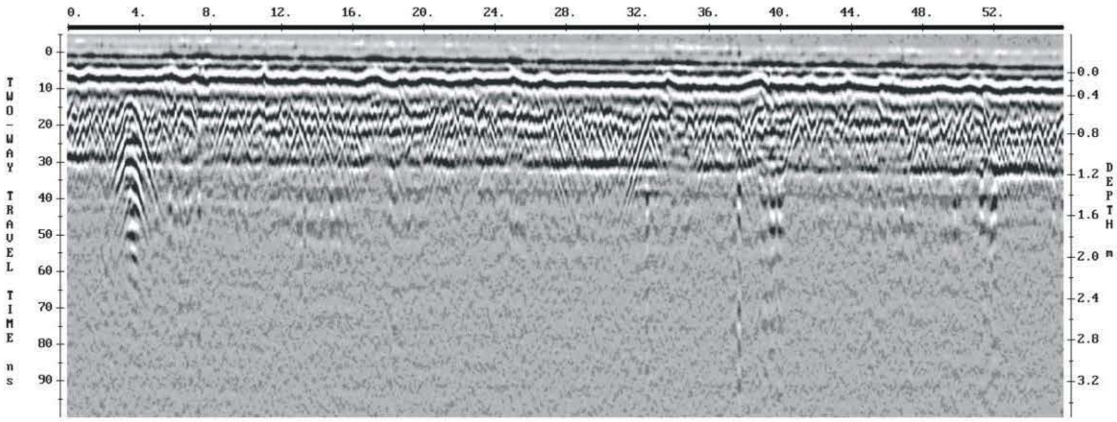
Line 13



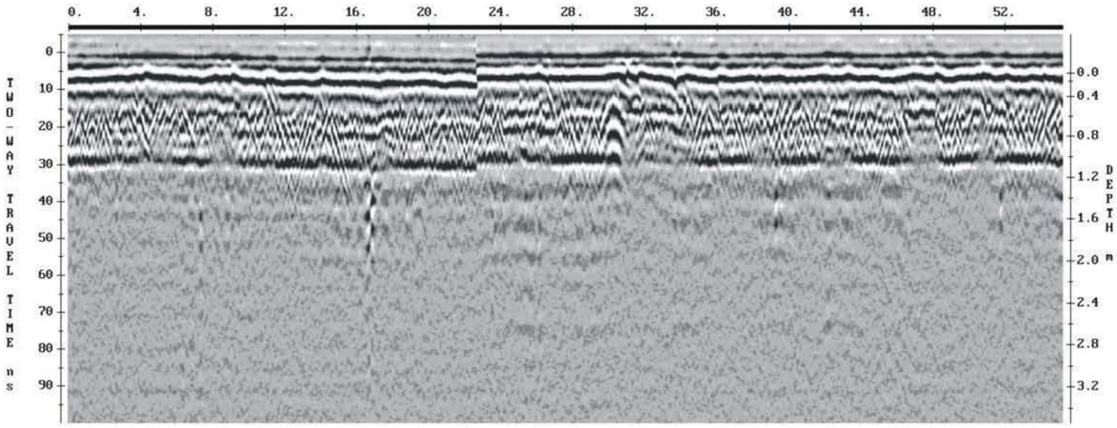
Line 14



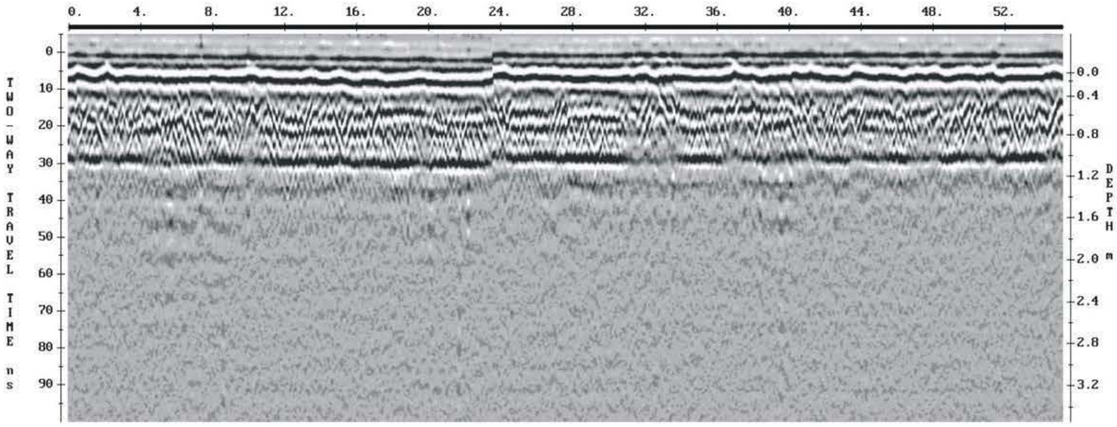
Line 15



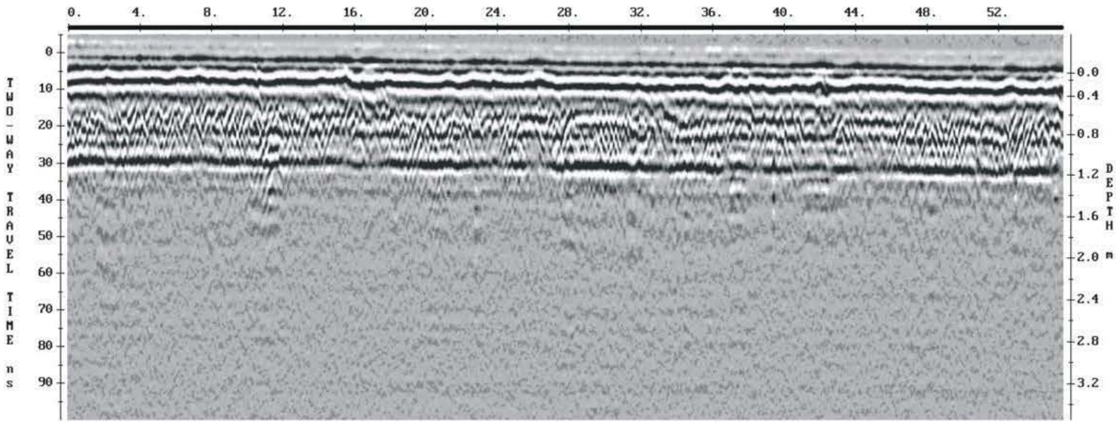
Line 16



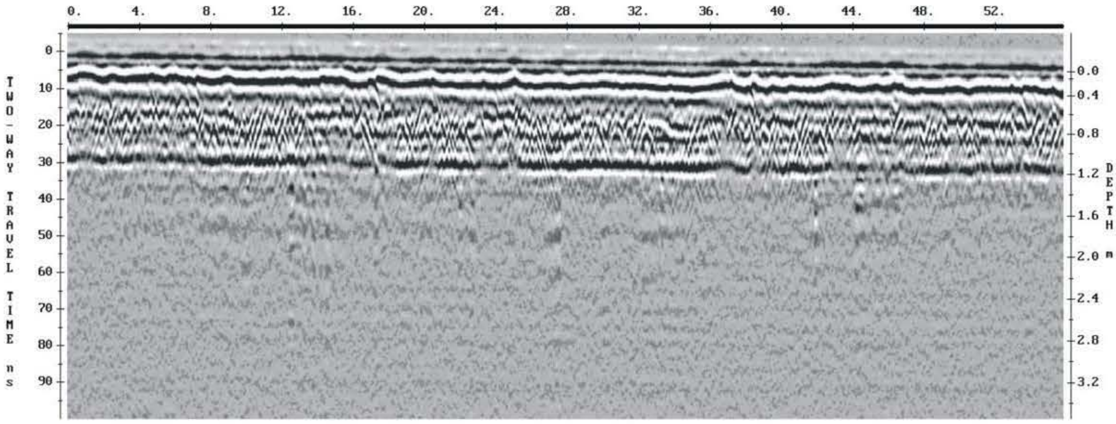
Line 17



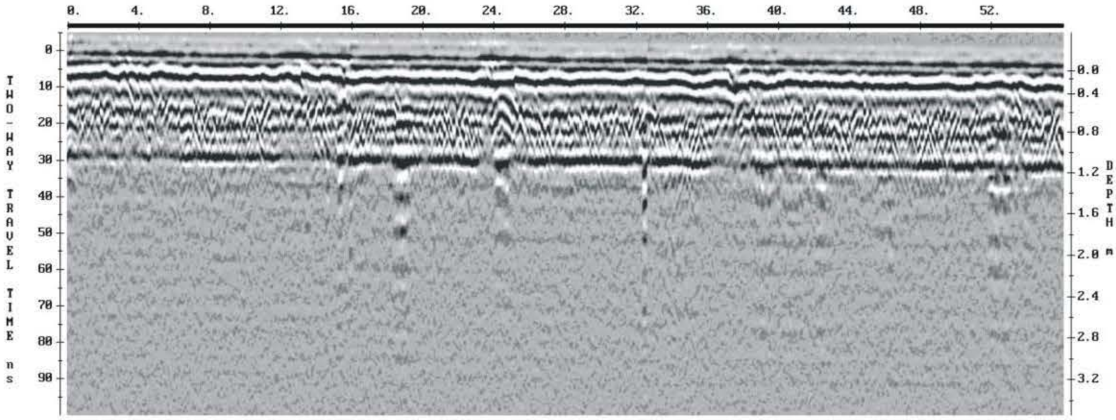
Line 18



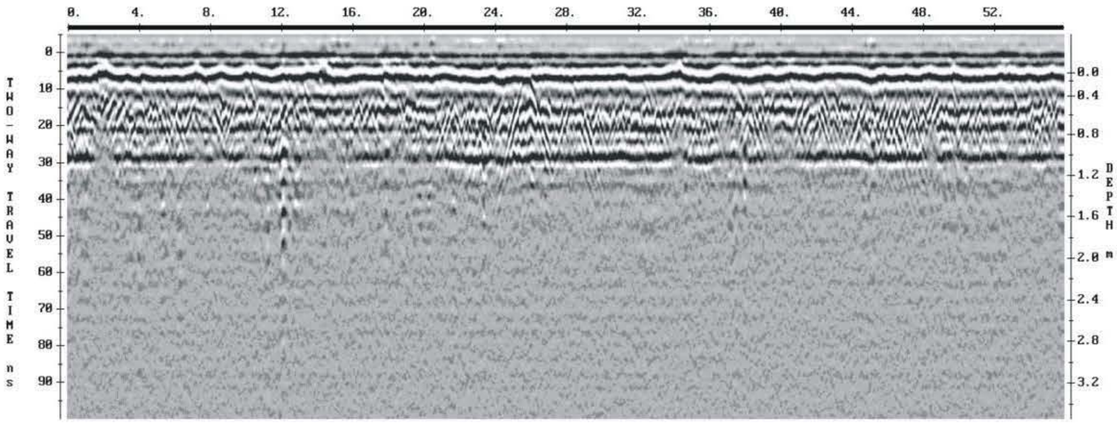
LINE 19



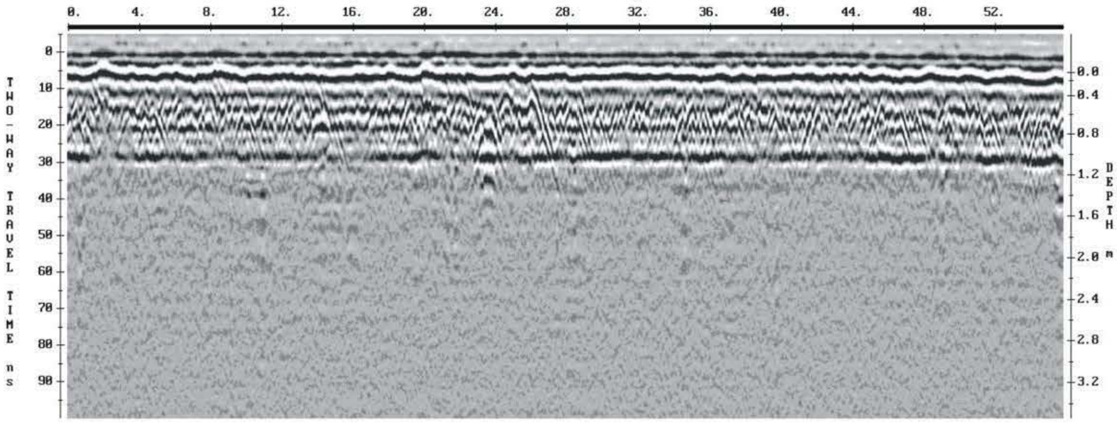
LINE 20



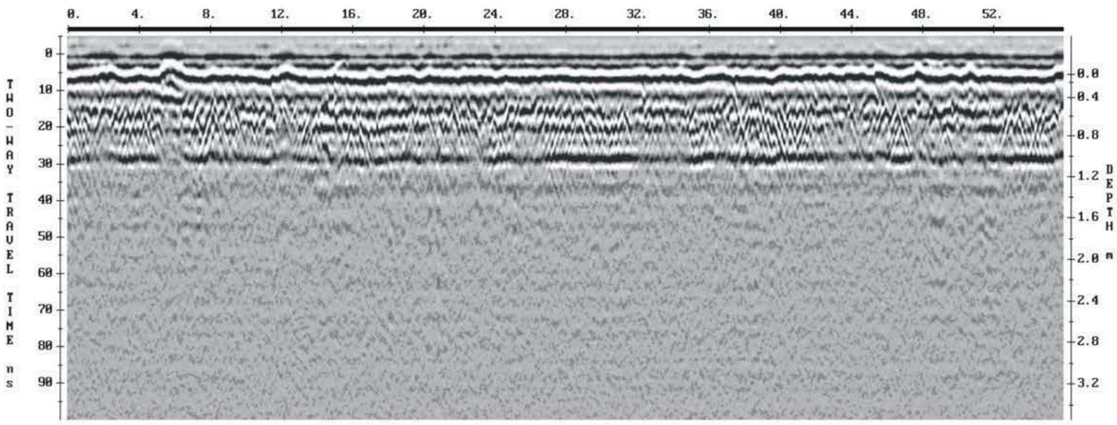
LINE 21



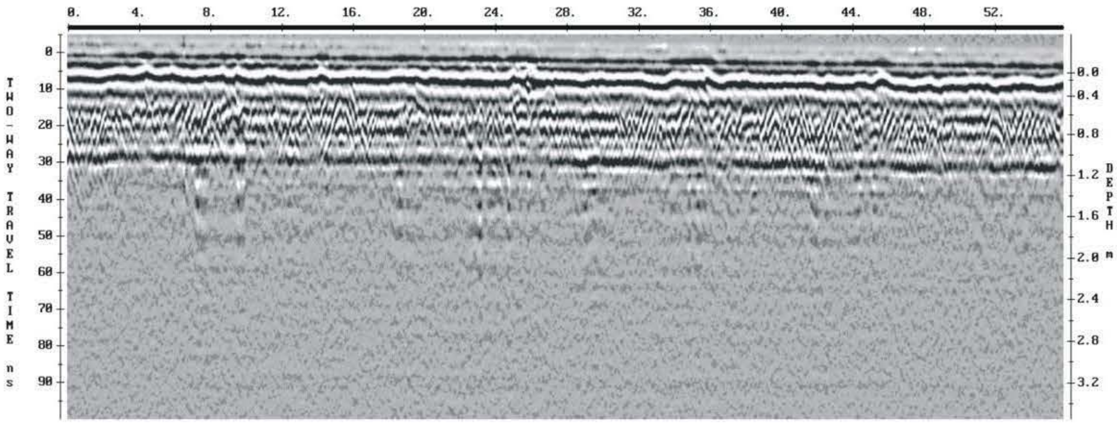
Line 22



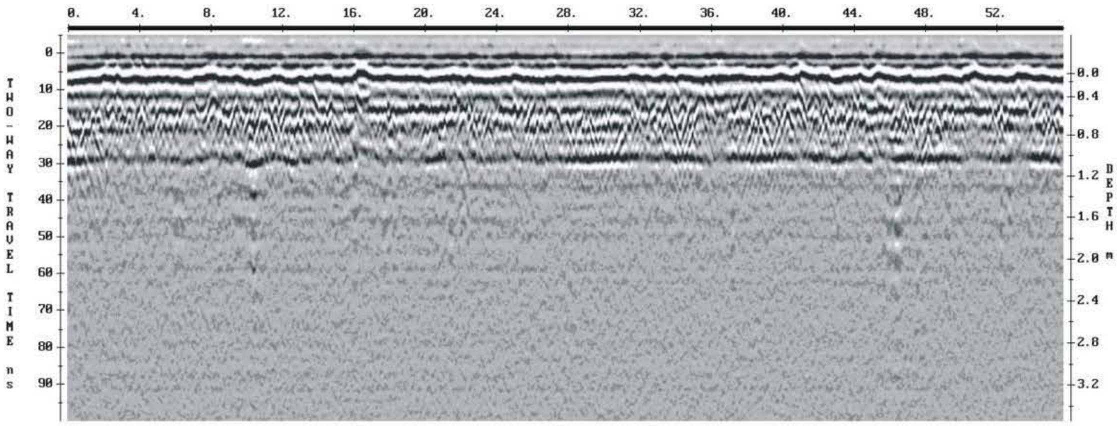
Line 23



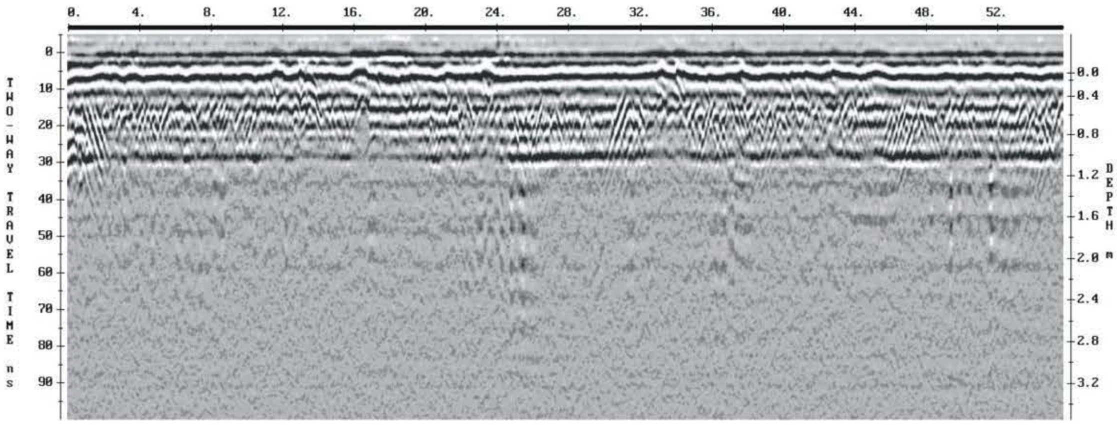
Line 24



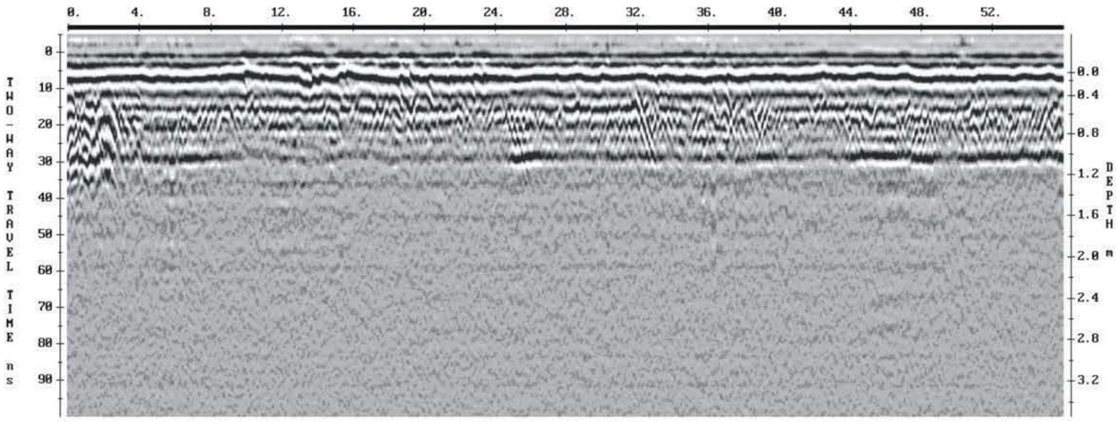
Line 25



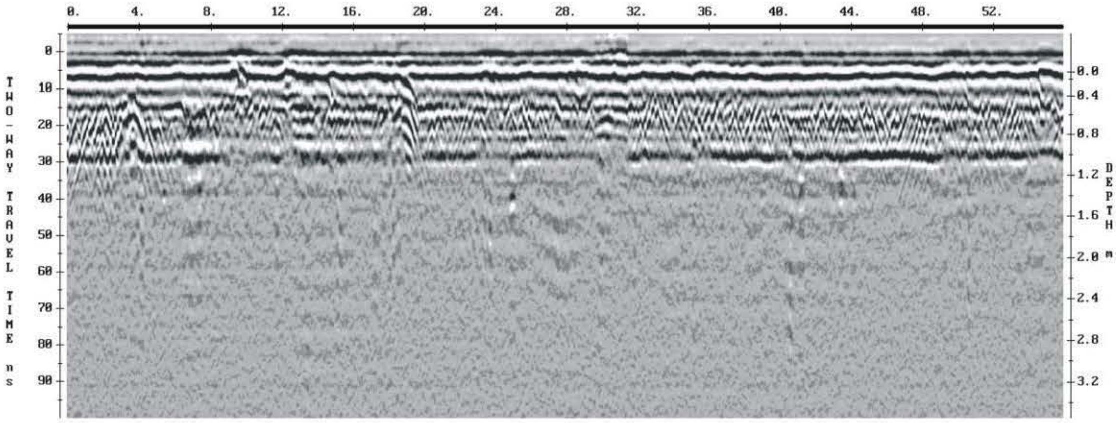
Line 26



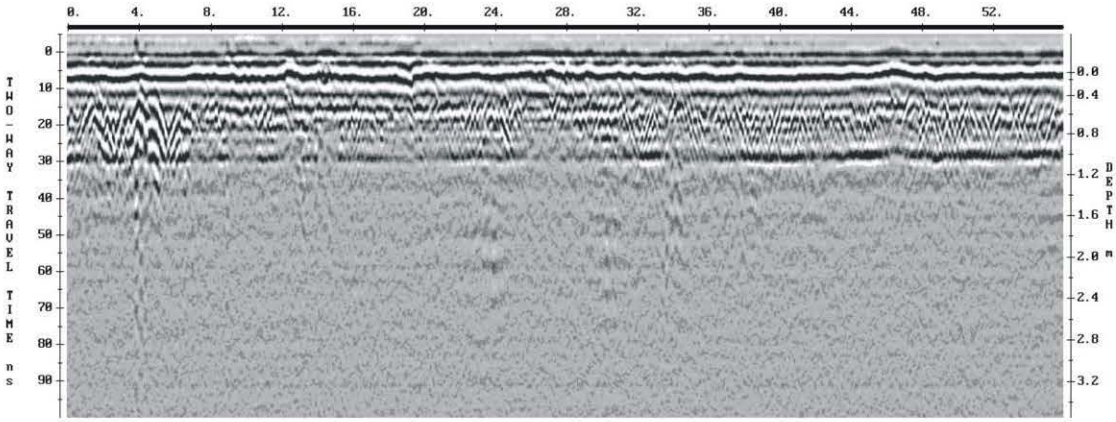
Line 27



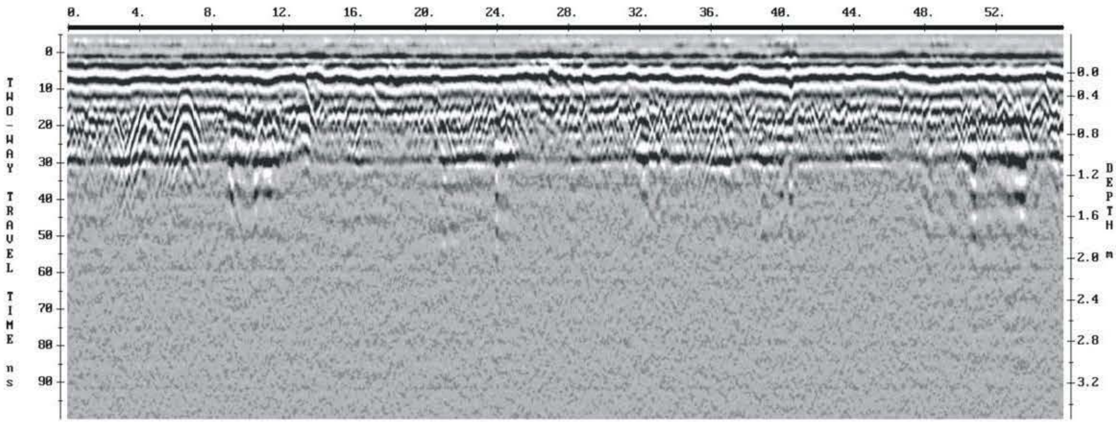
Line 28



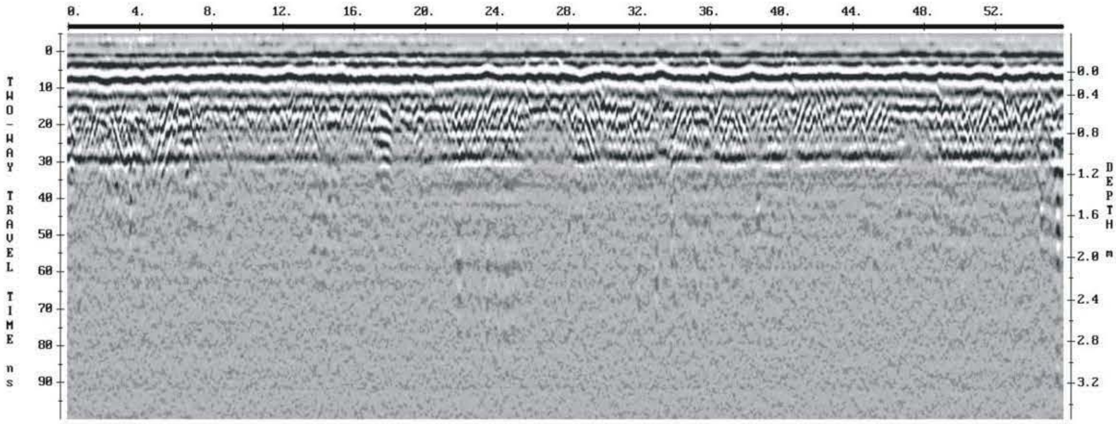
Line 29



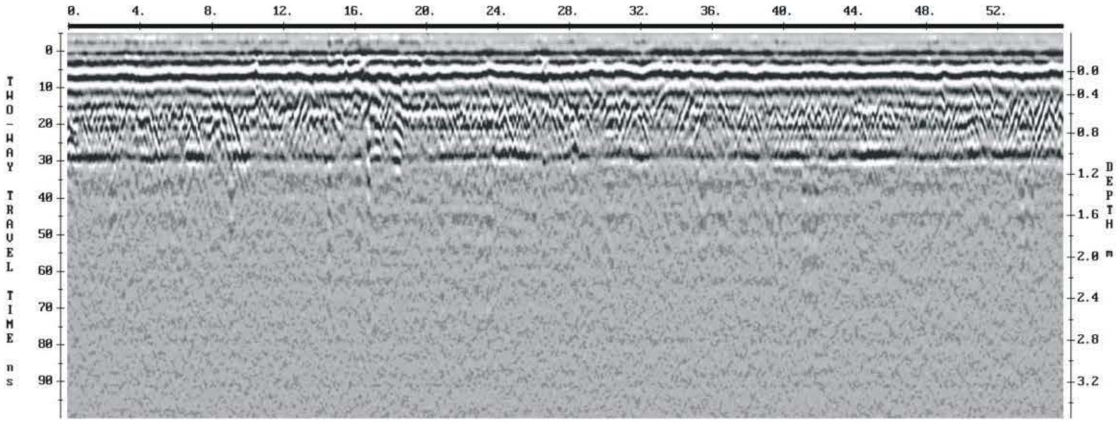
Line 30



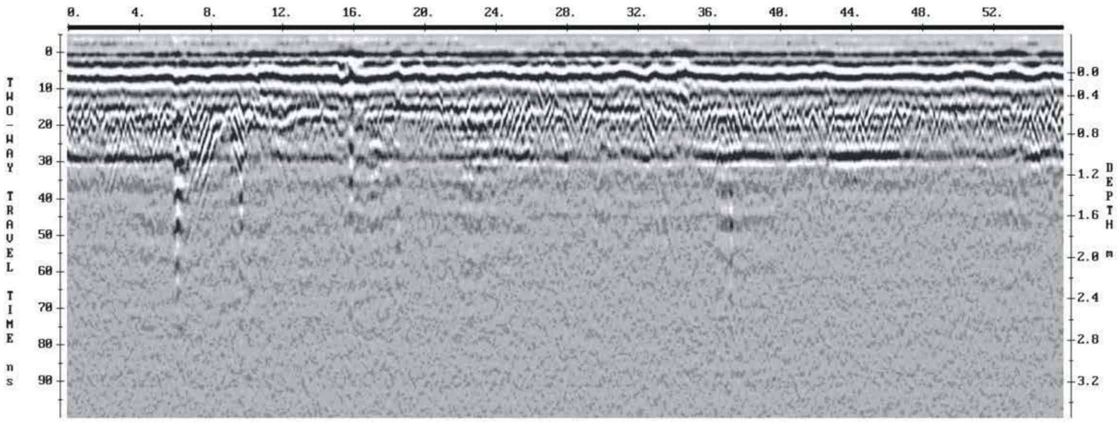
Line 31



Line 32



Line 33



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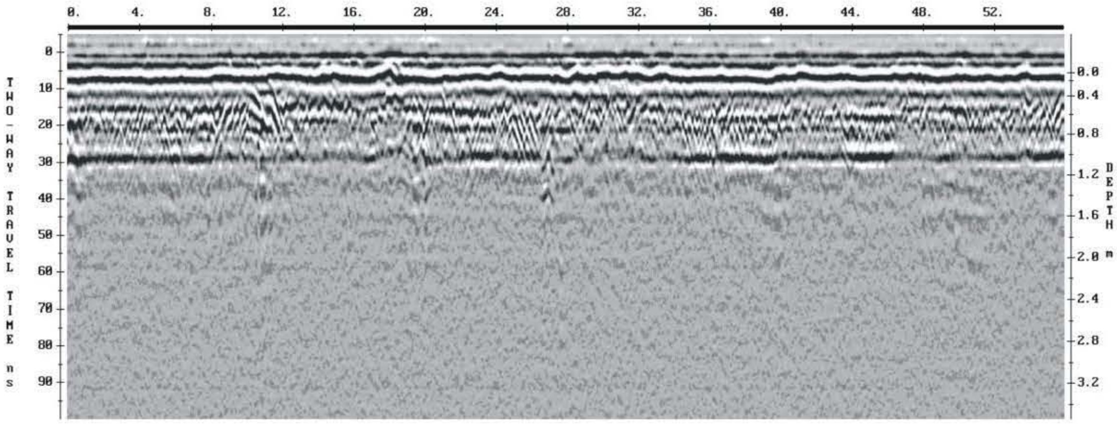

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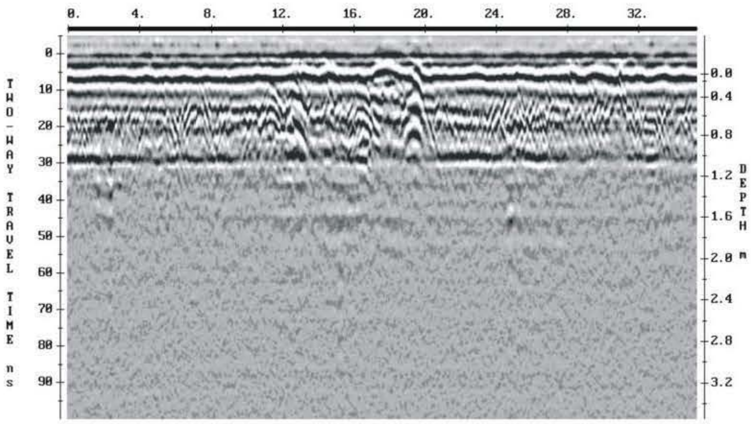

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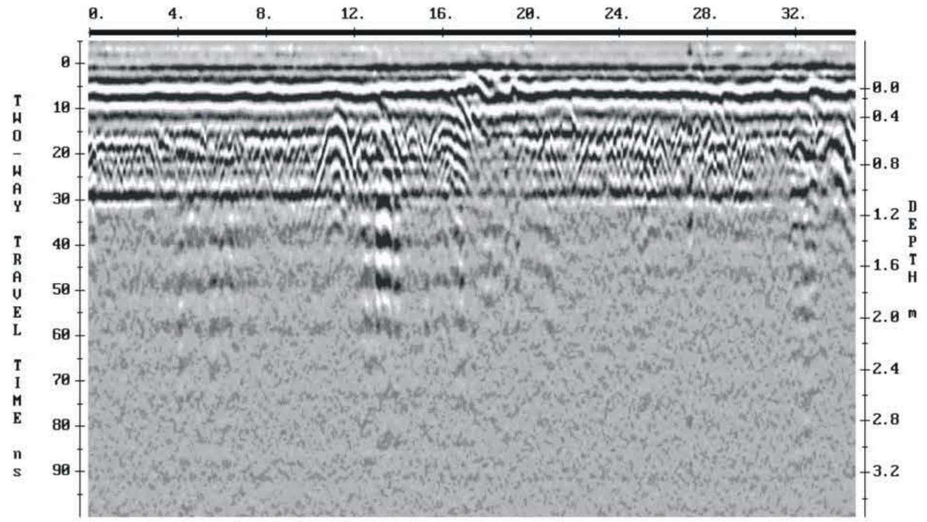

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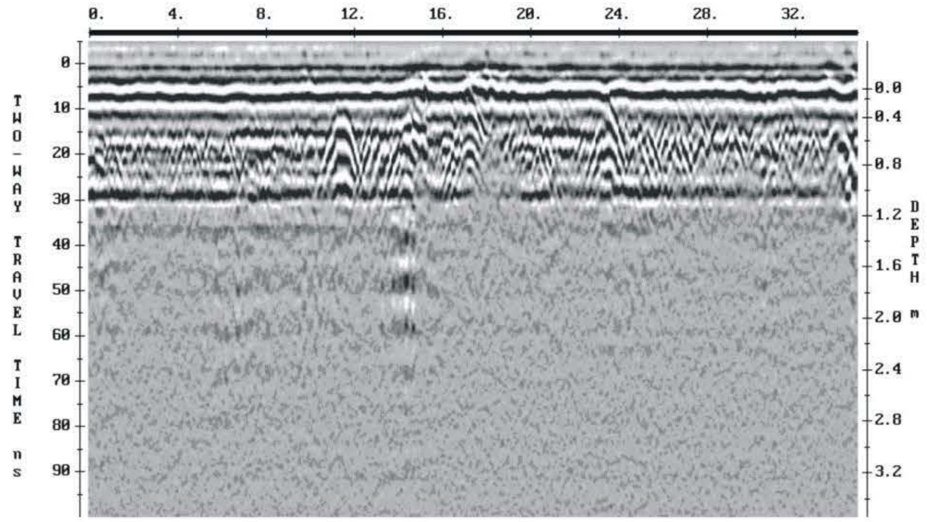

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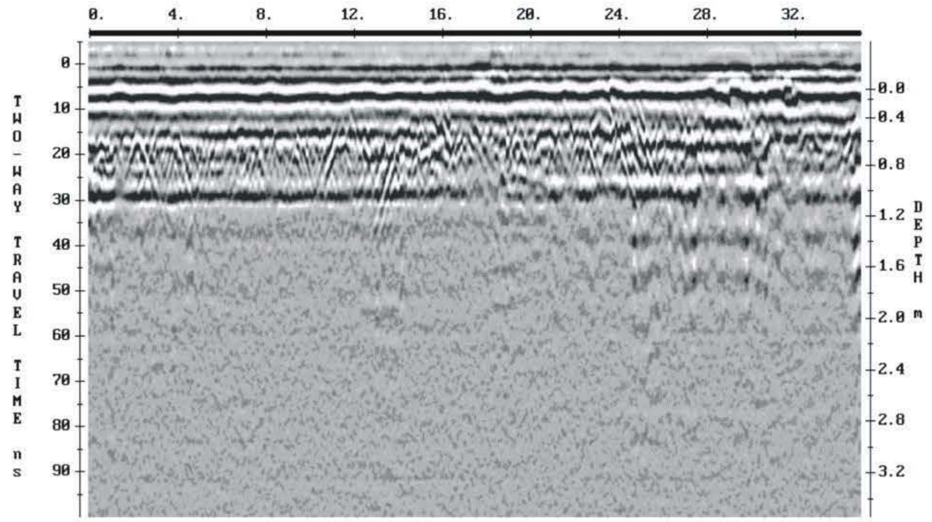

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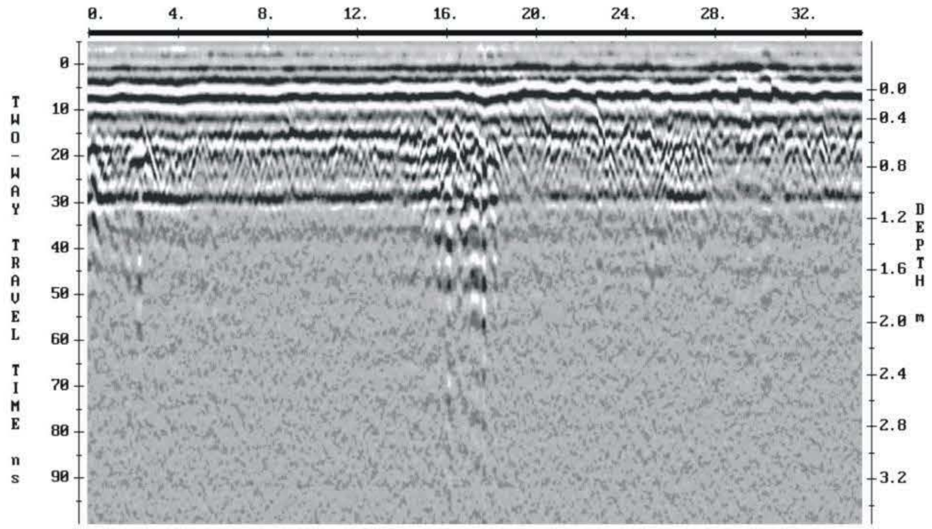

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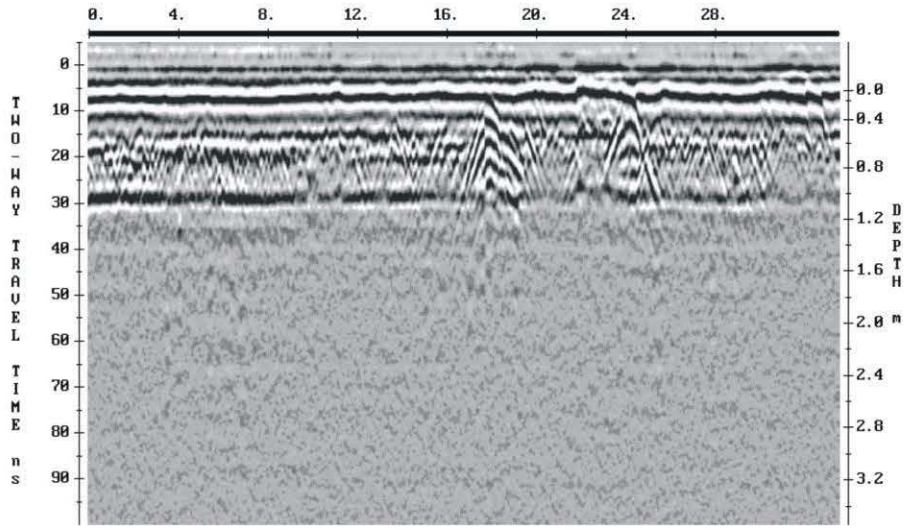

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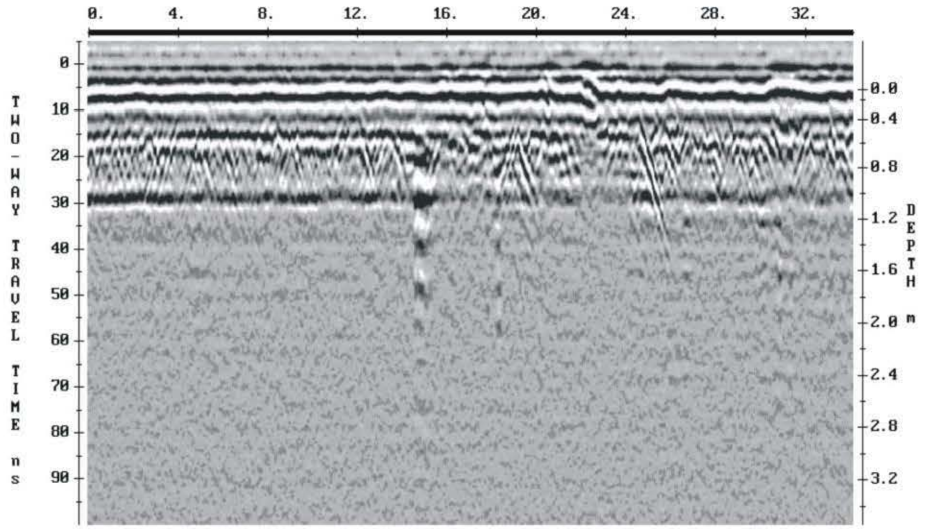

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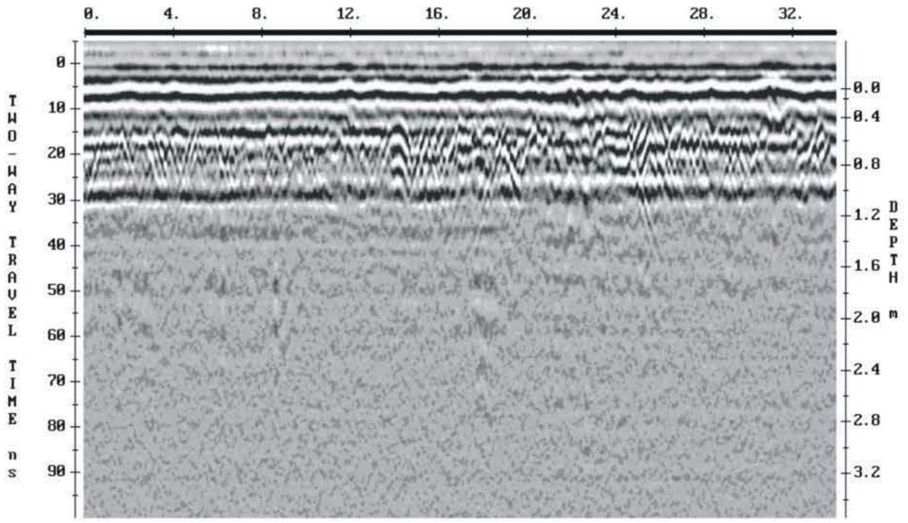

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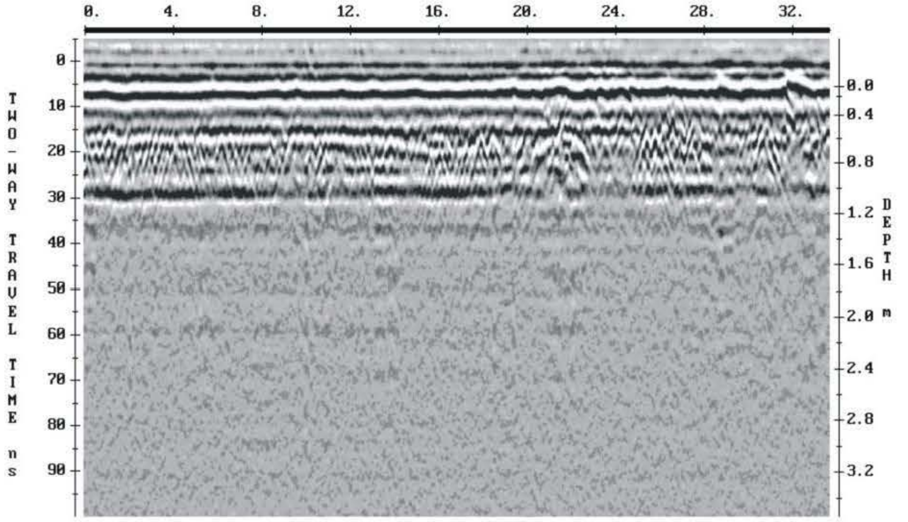

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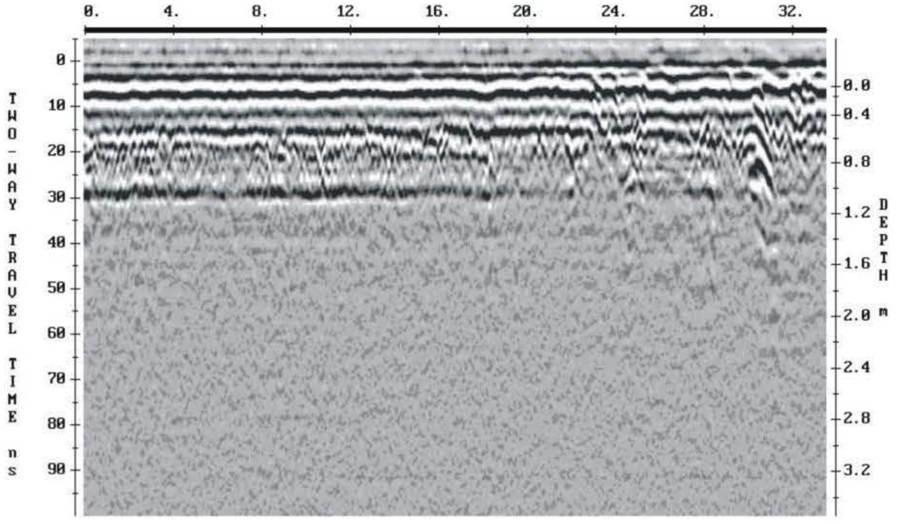

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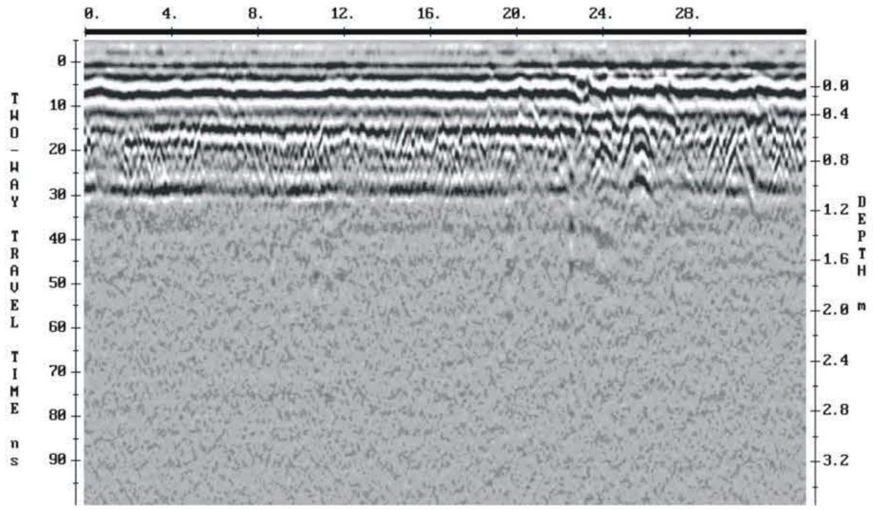

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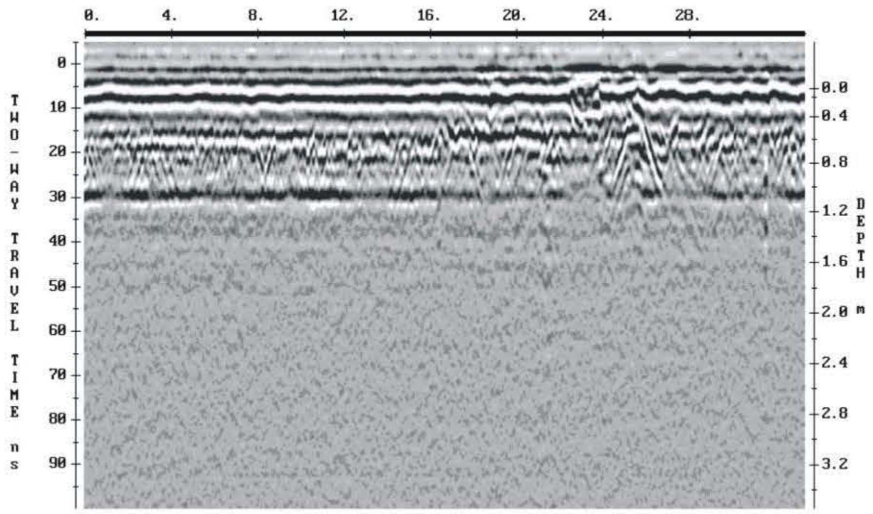

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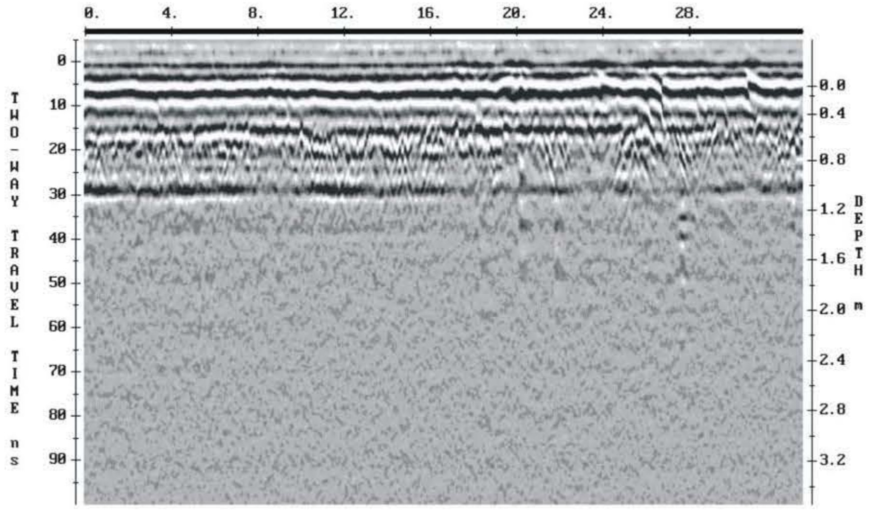

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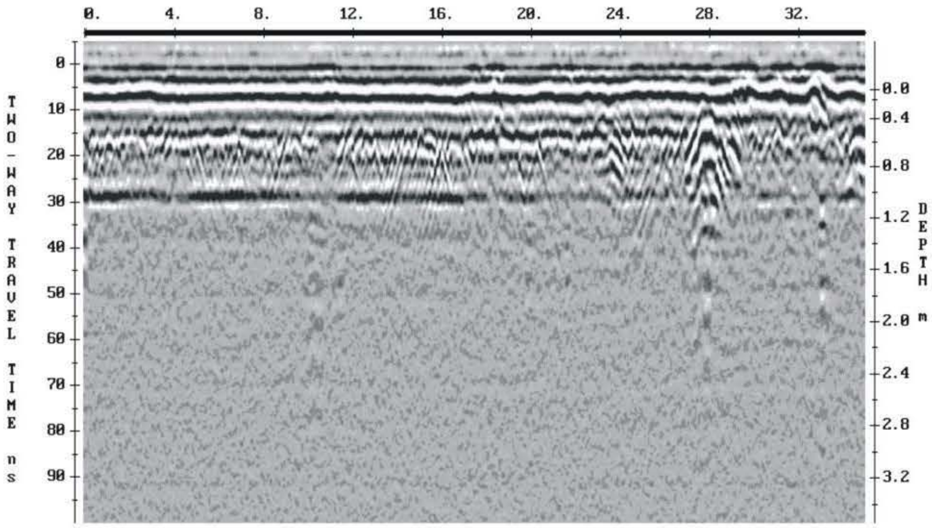

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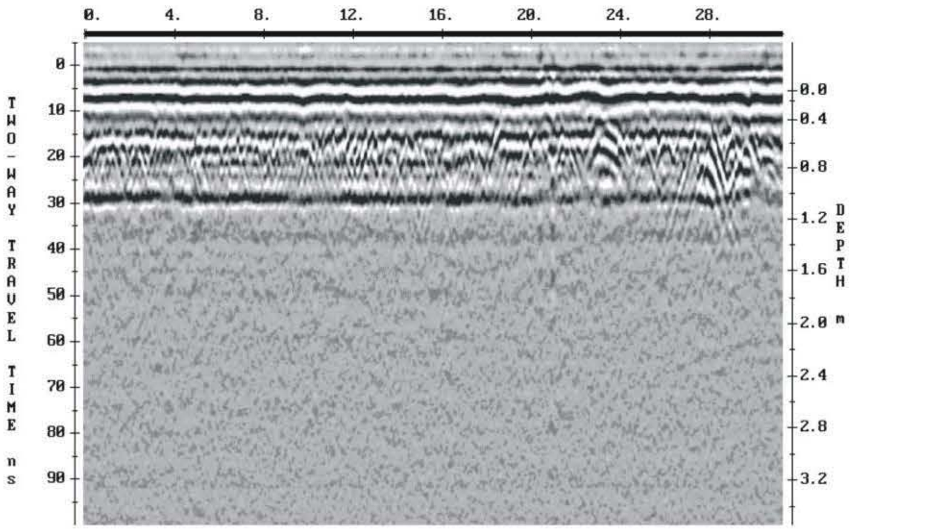

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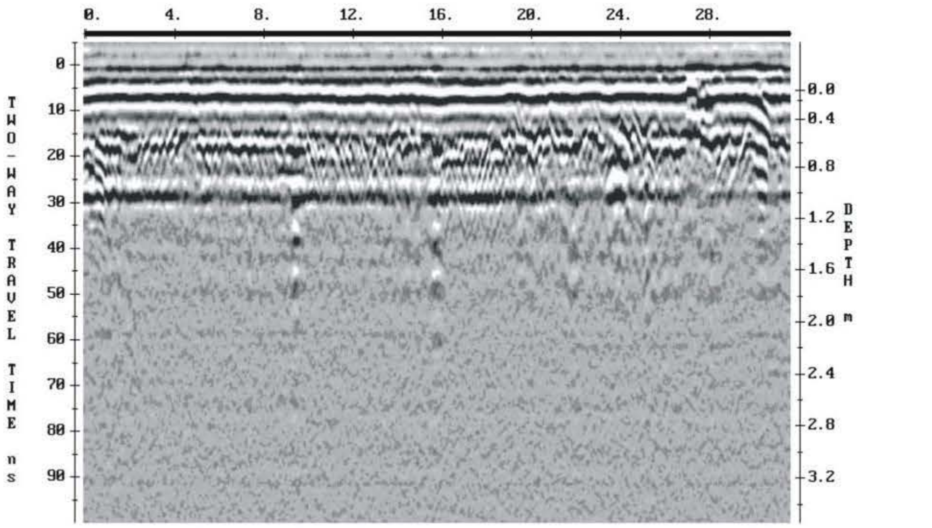

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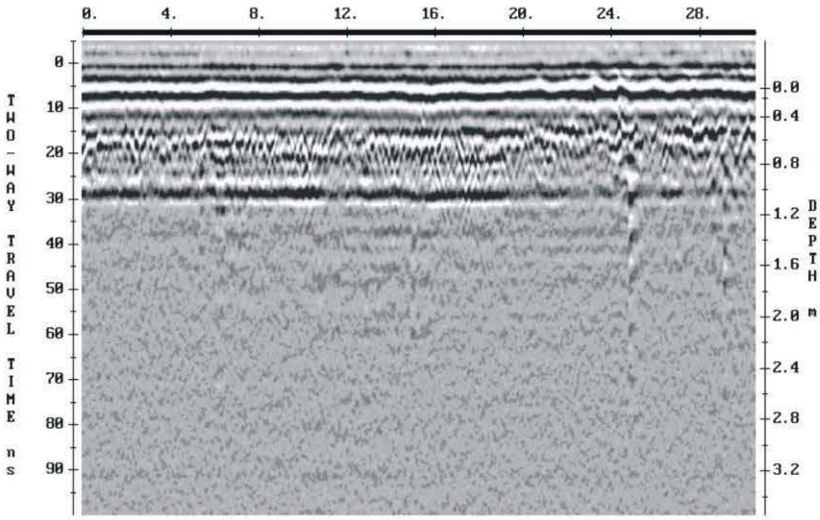

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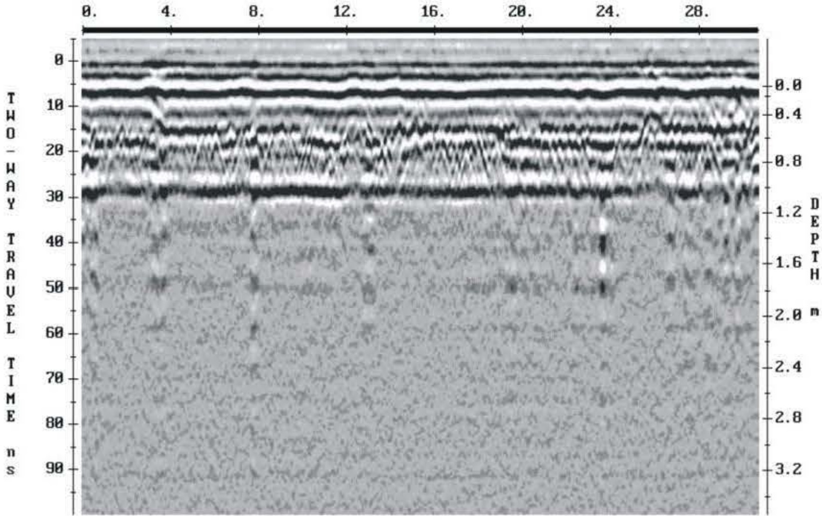

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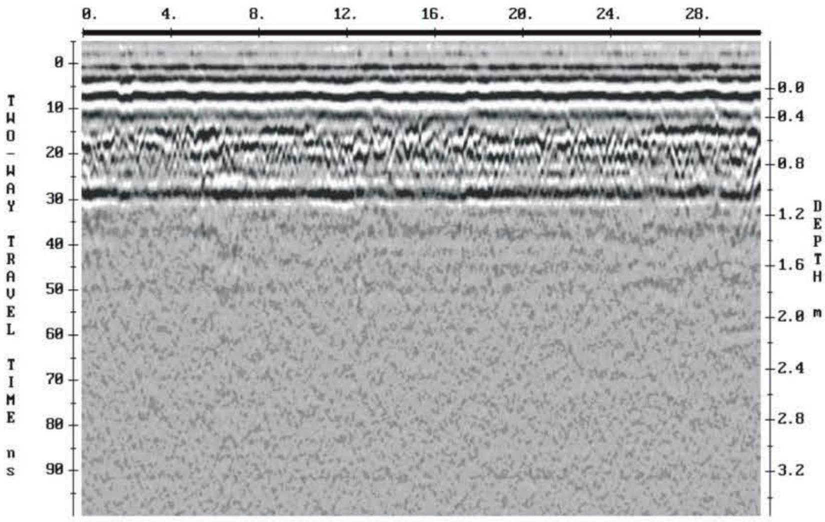

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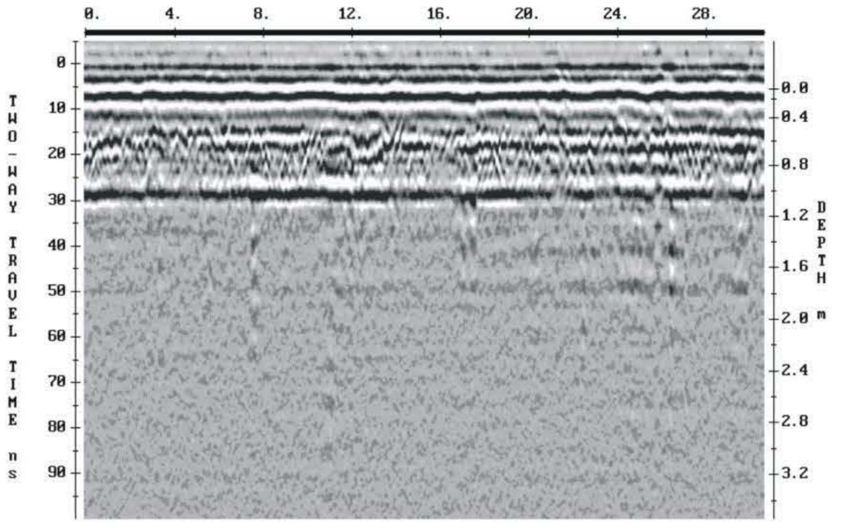

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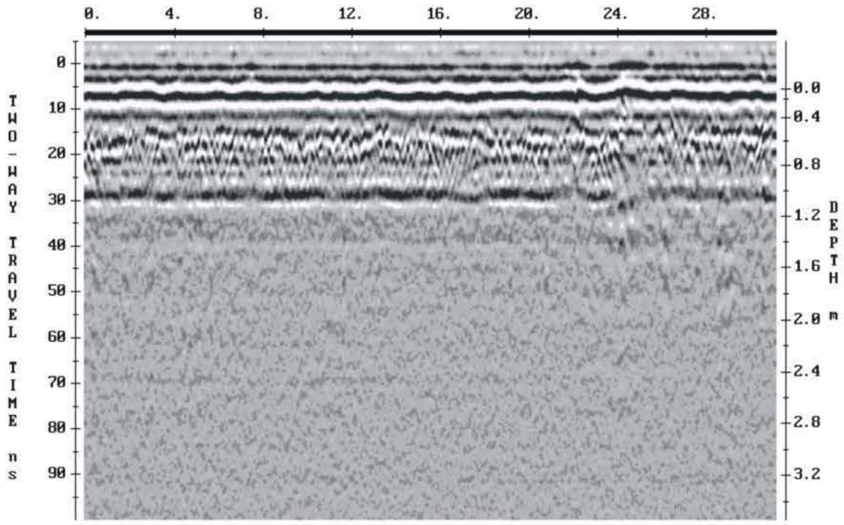

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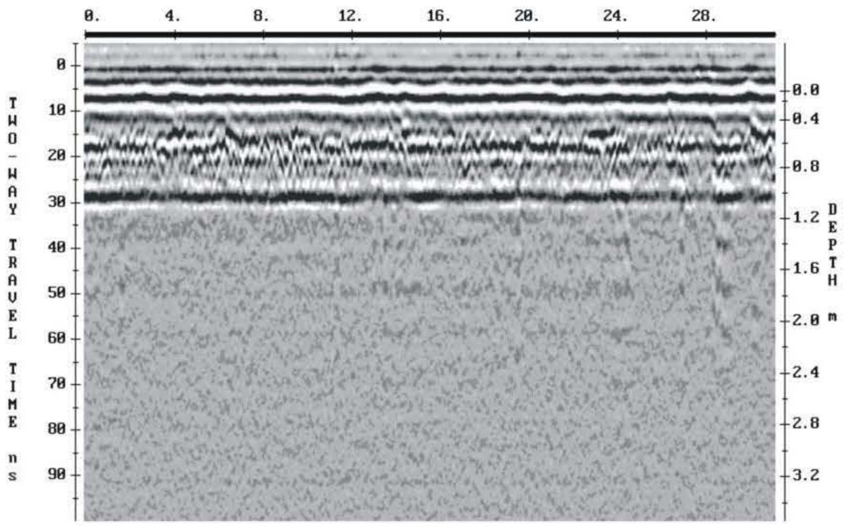

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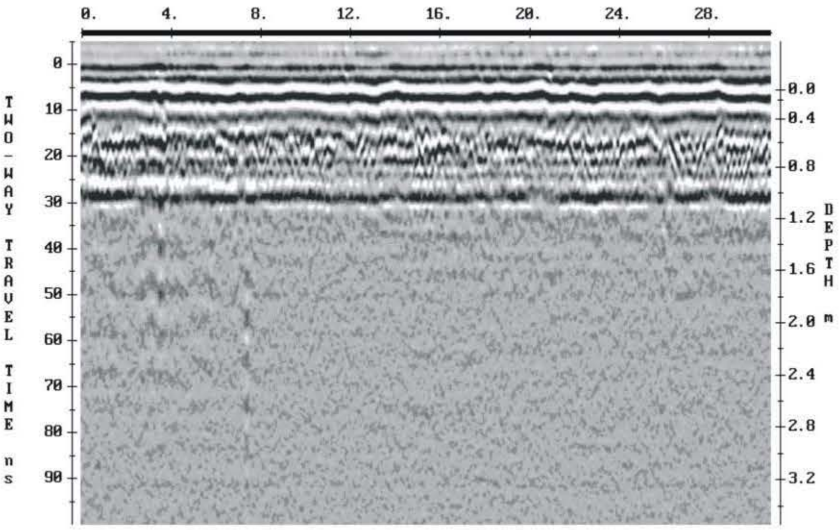

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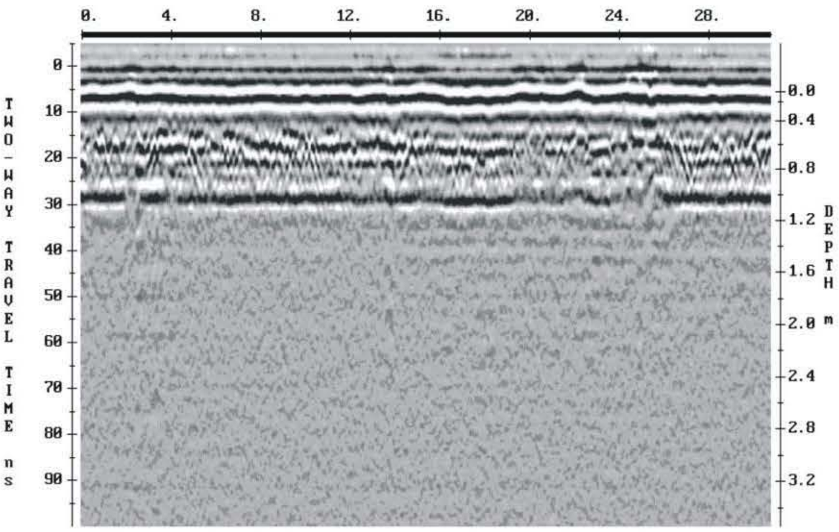

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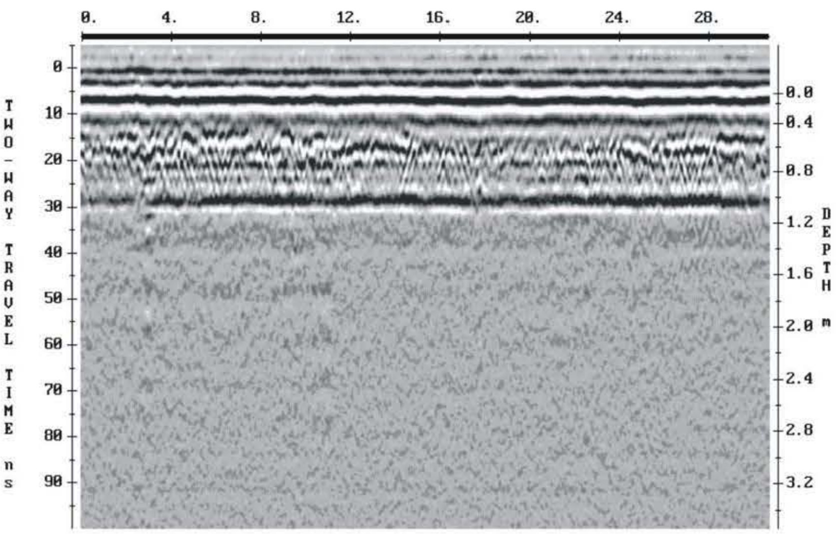

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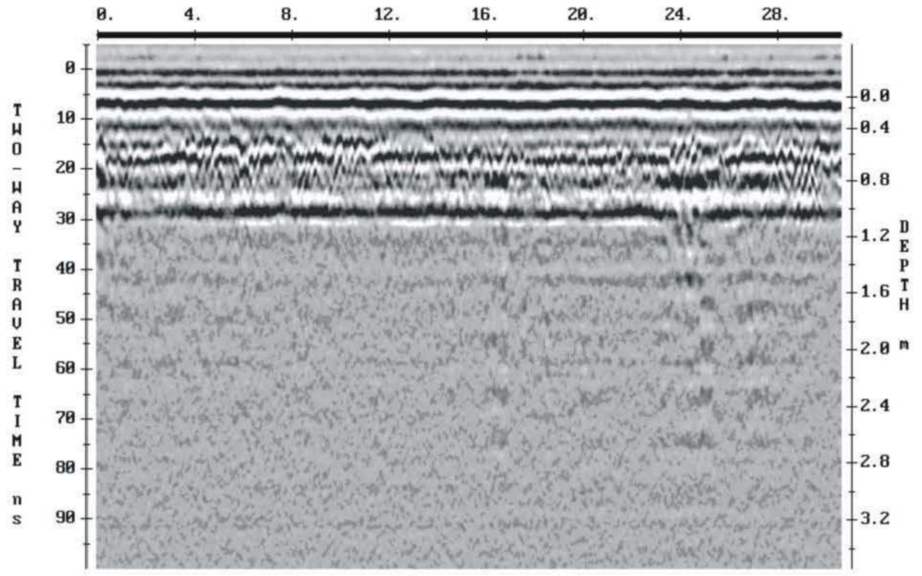

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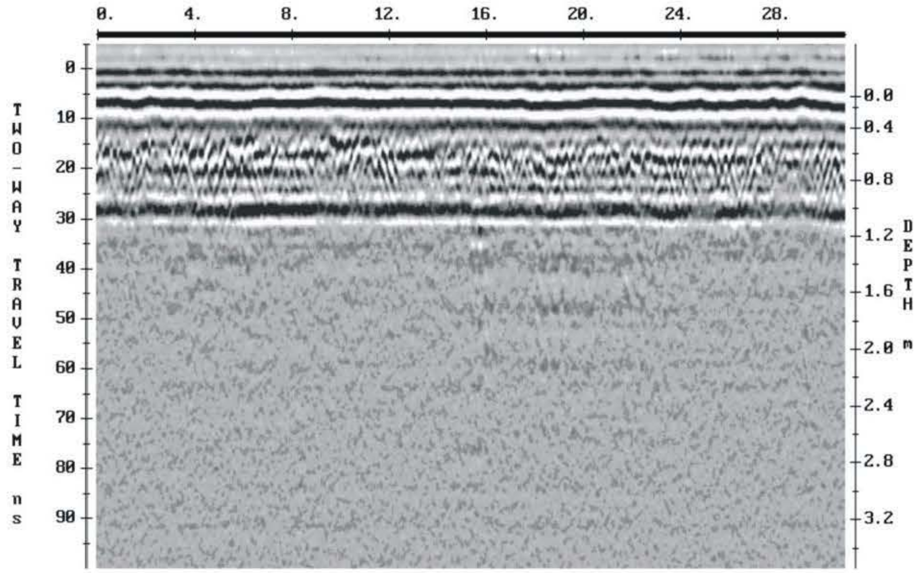
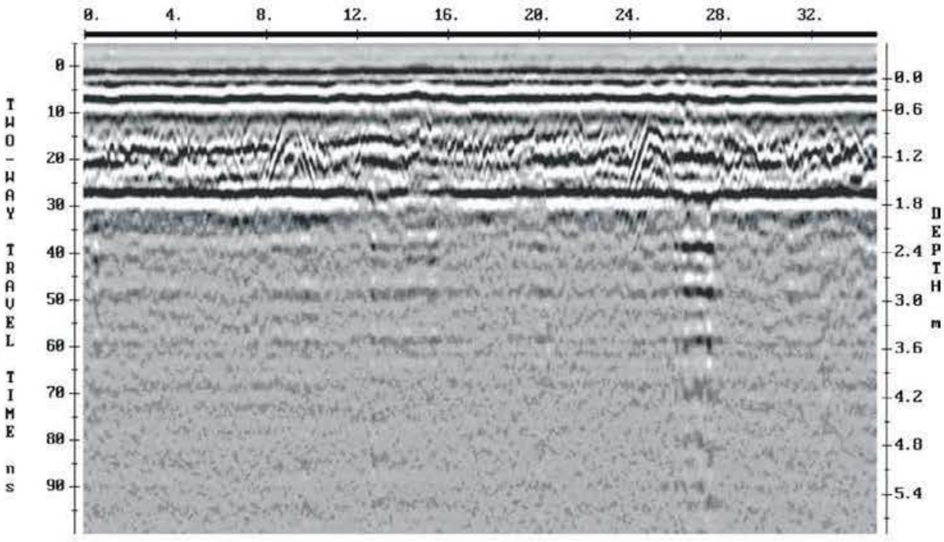


Line 62

APPENDIX IV
GPR SURVEYS
(part 2 of 3)

KOUKOURARATA
Lower survey grid
225 MHz Frequency



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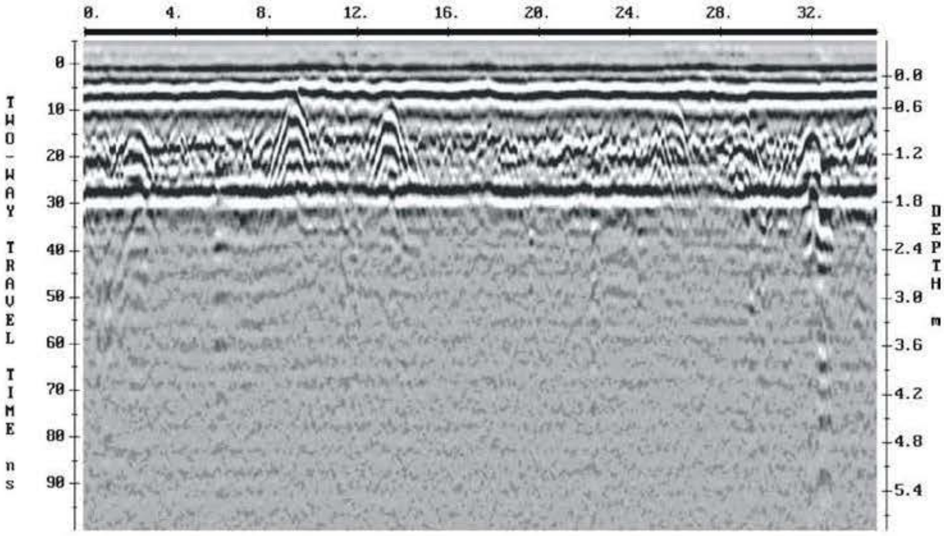

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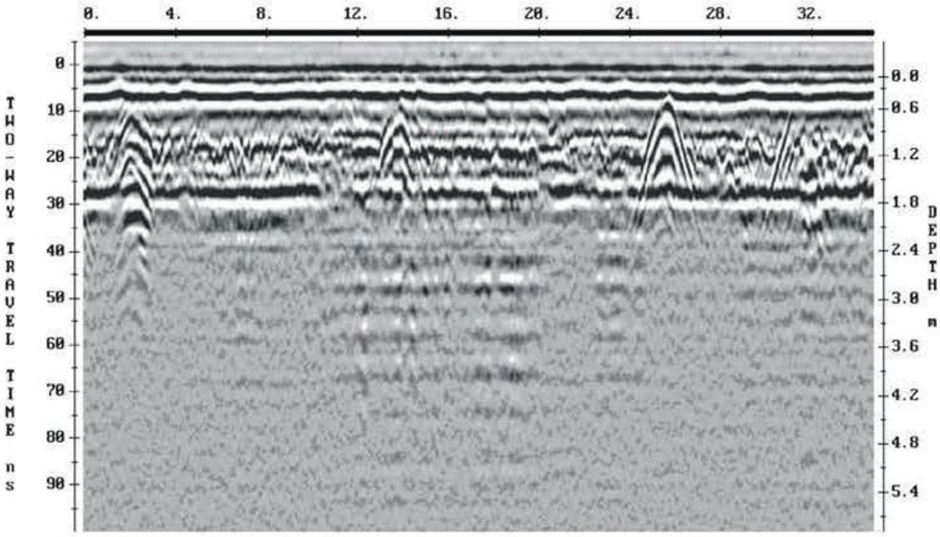

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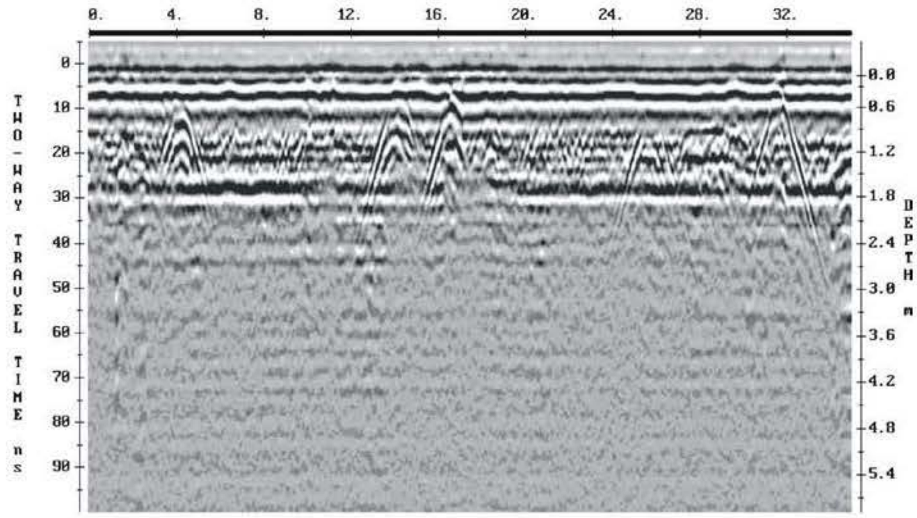

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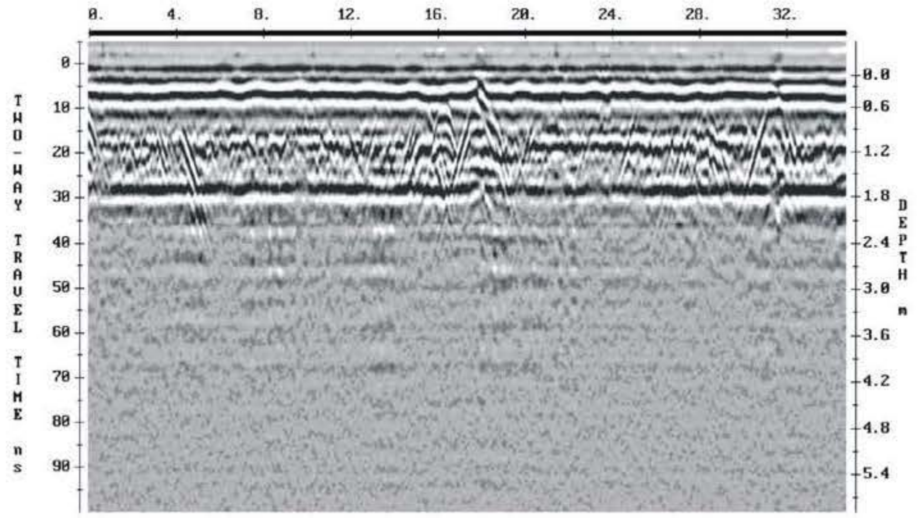

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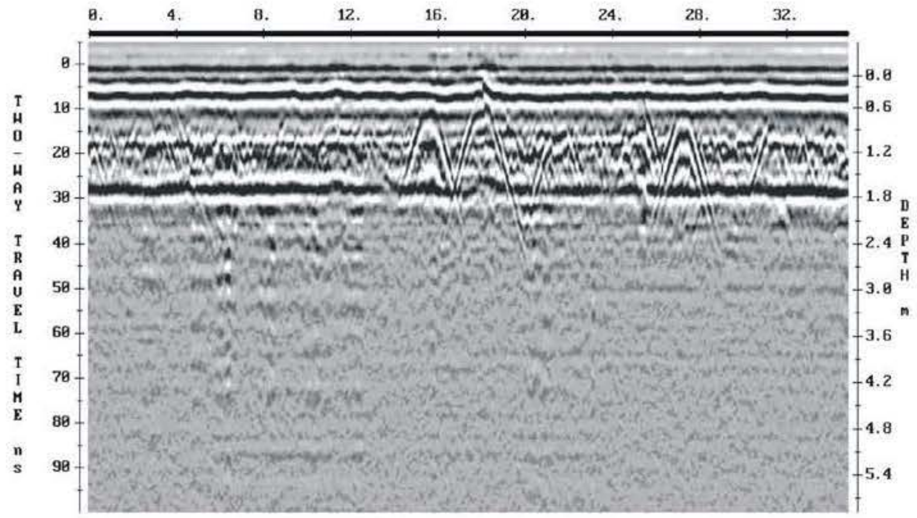

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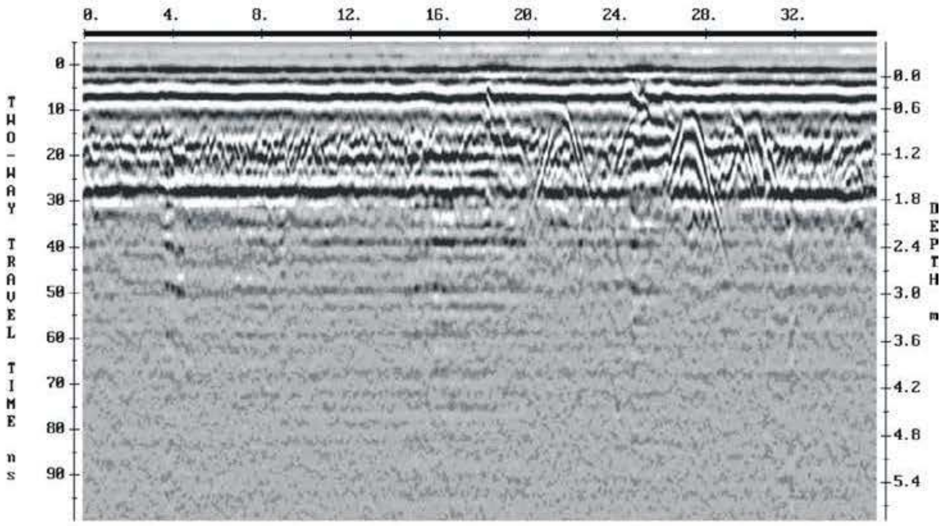

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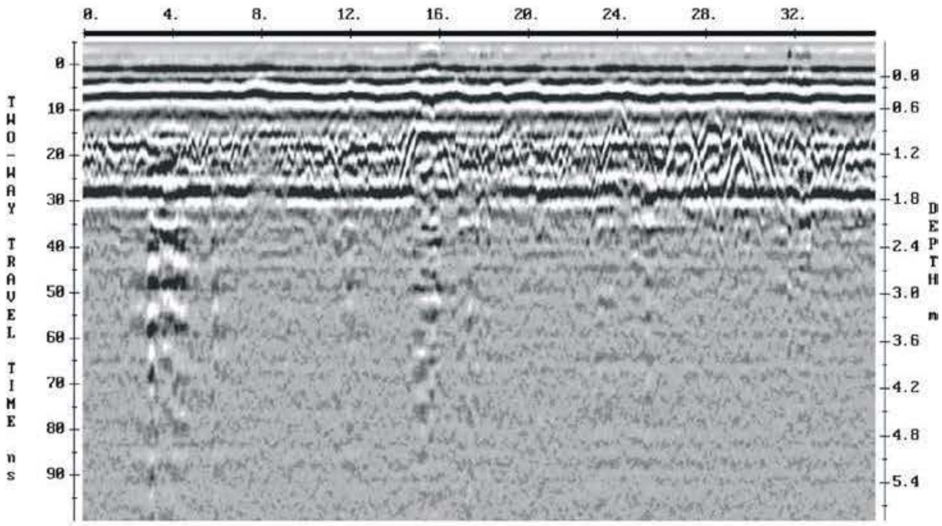

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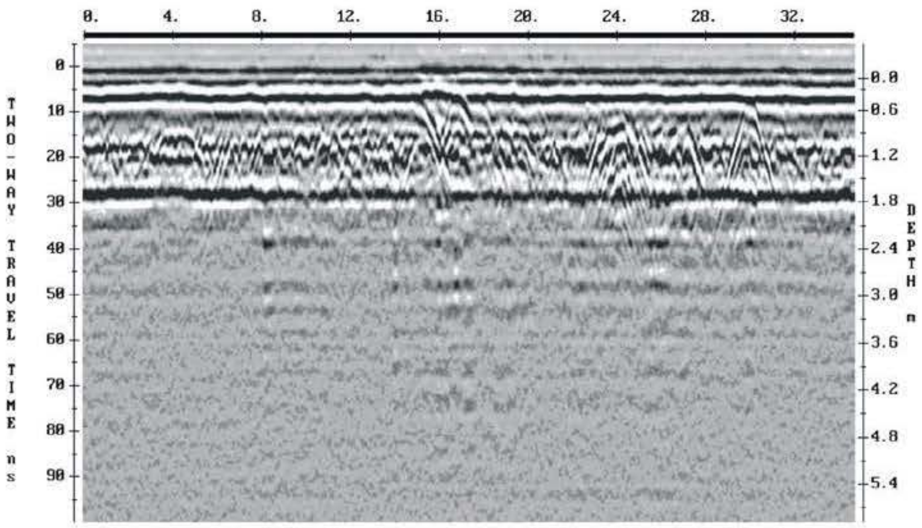

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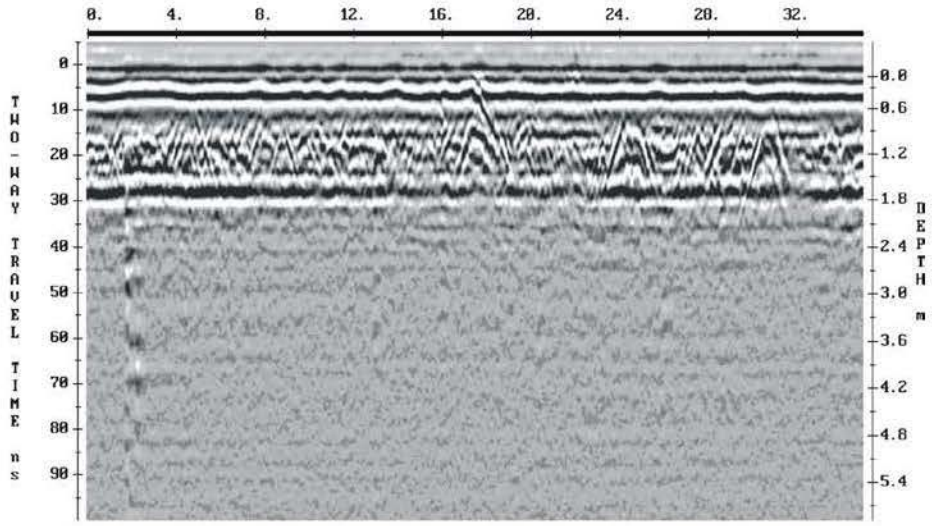

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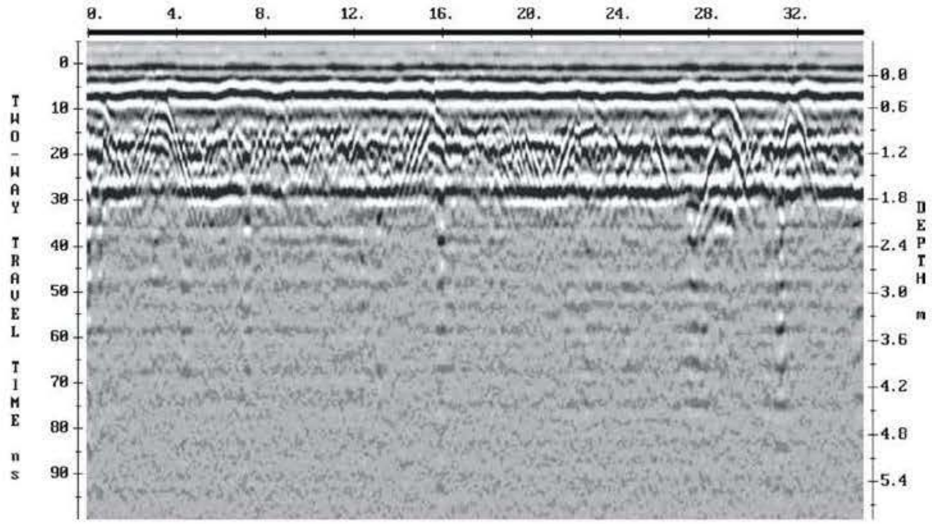

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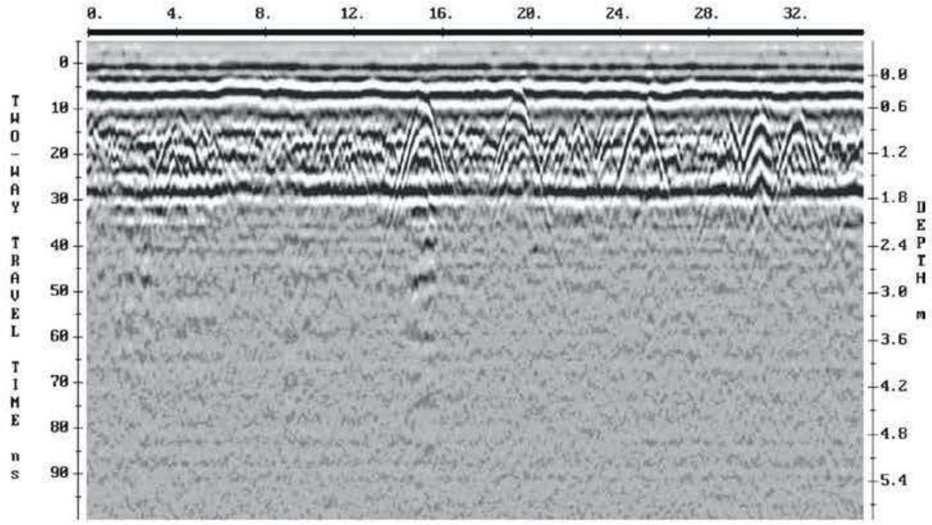

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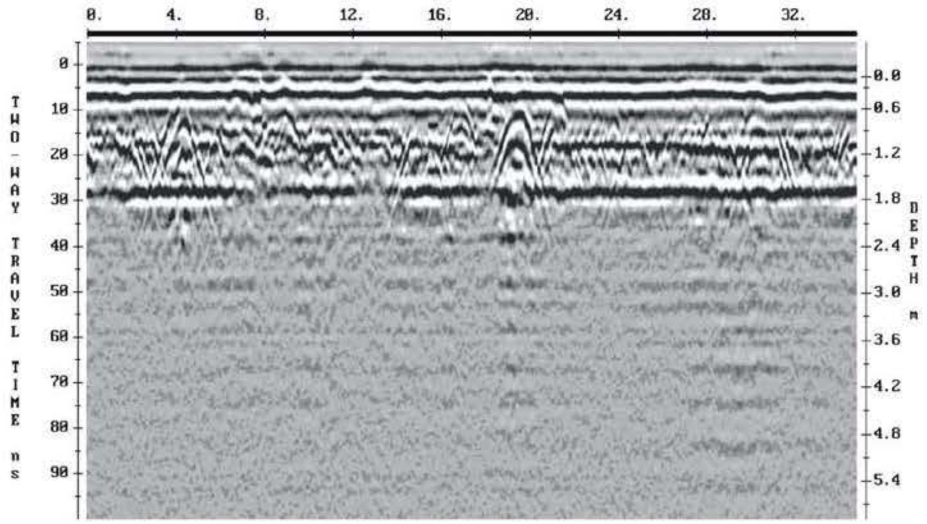

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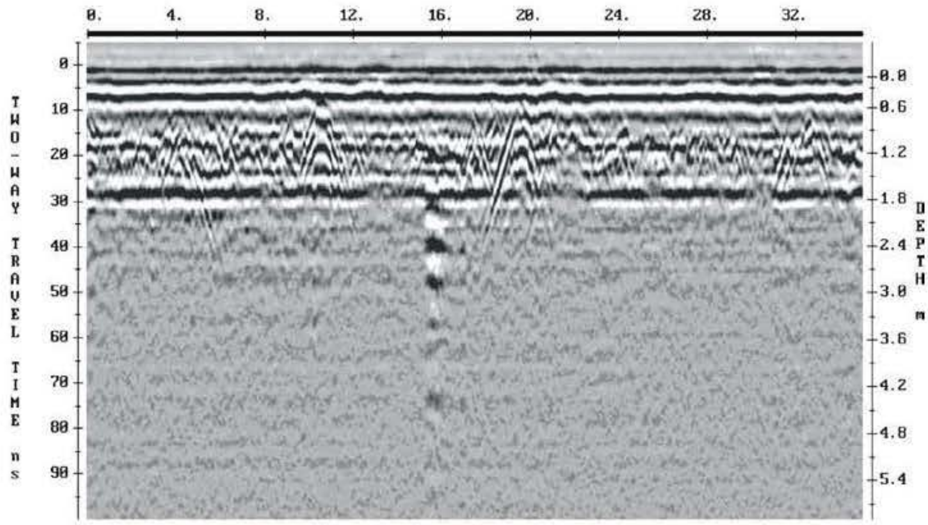

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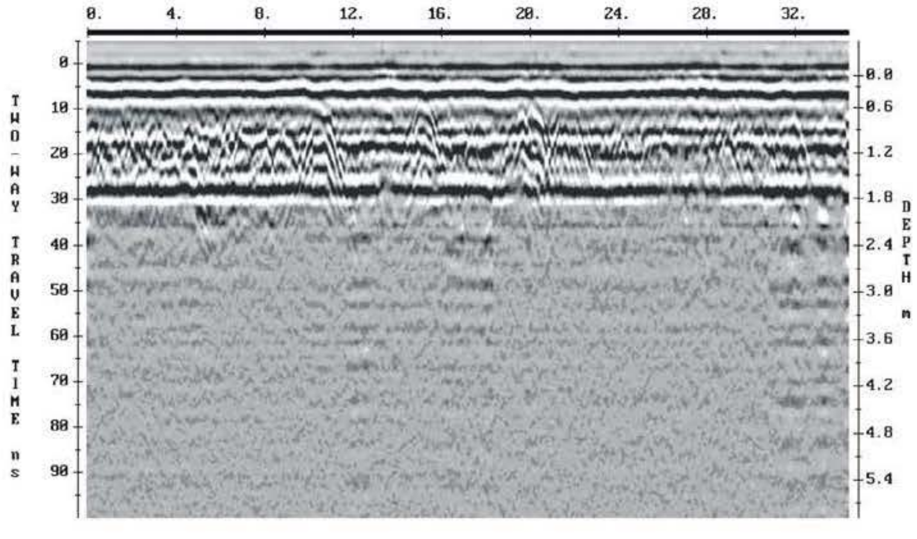

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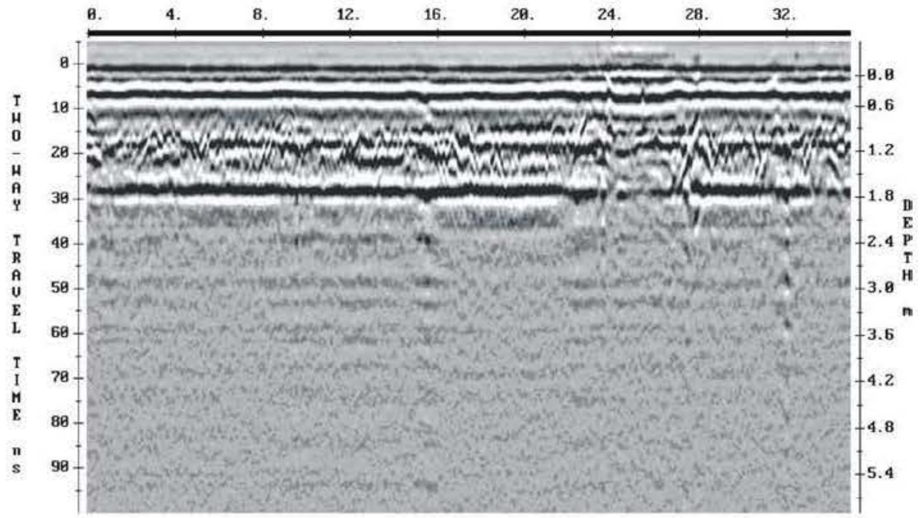

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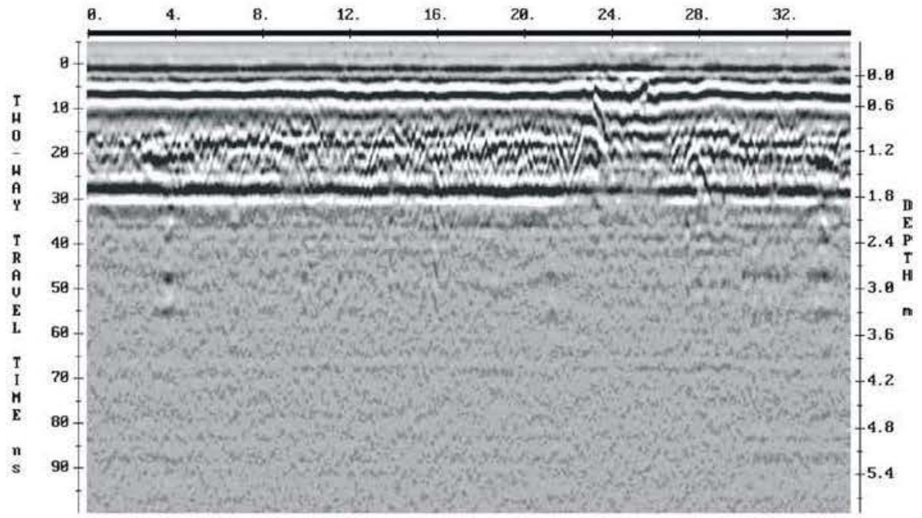

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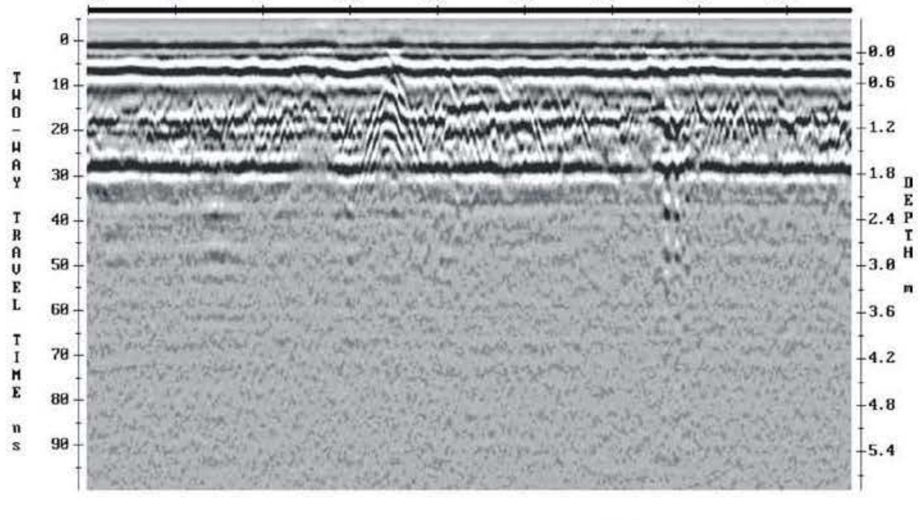

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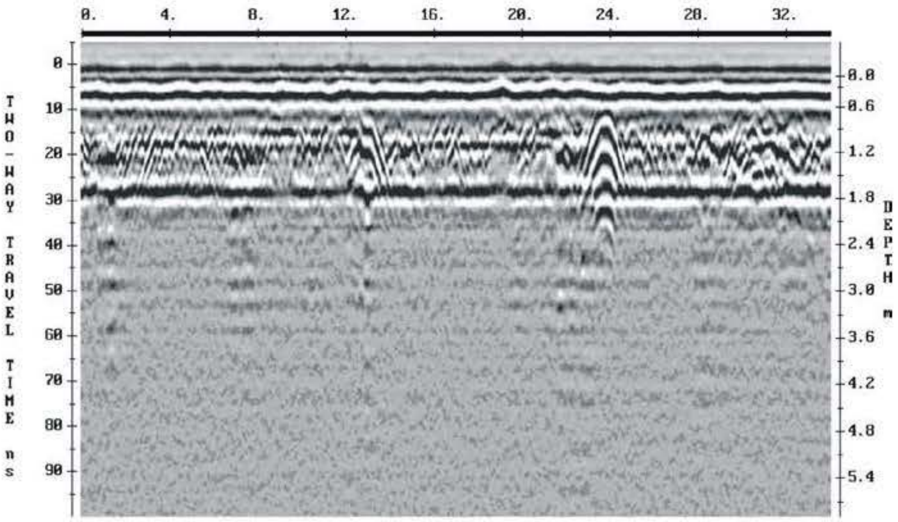

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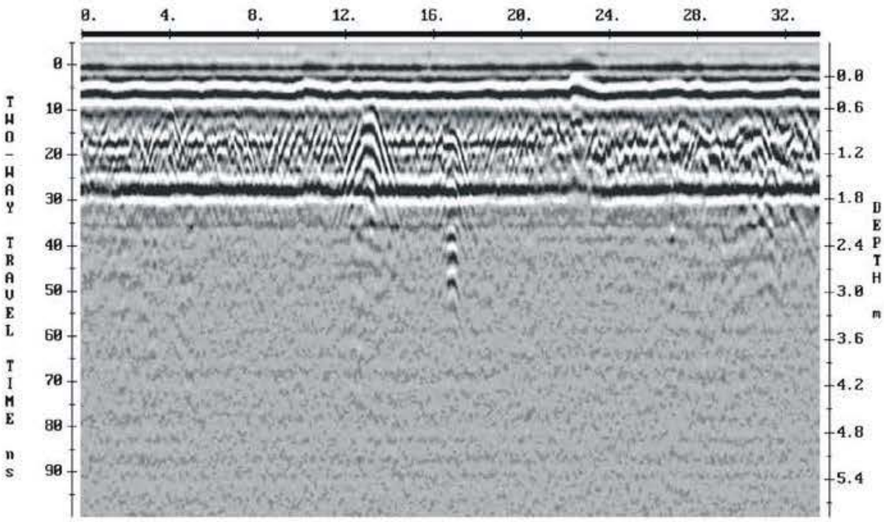

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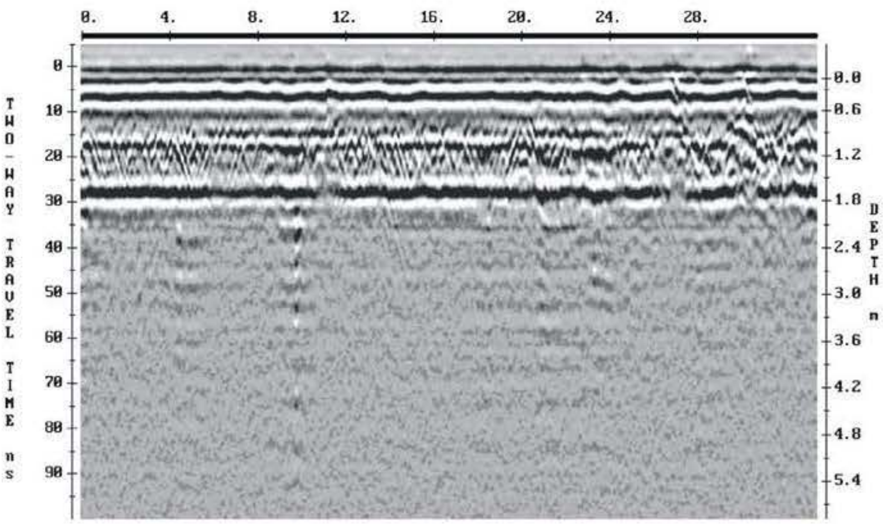

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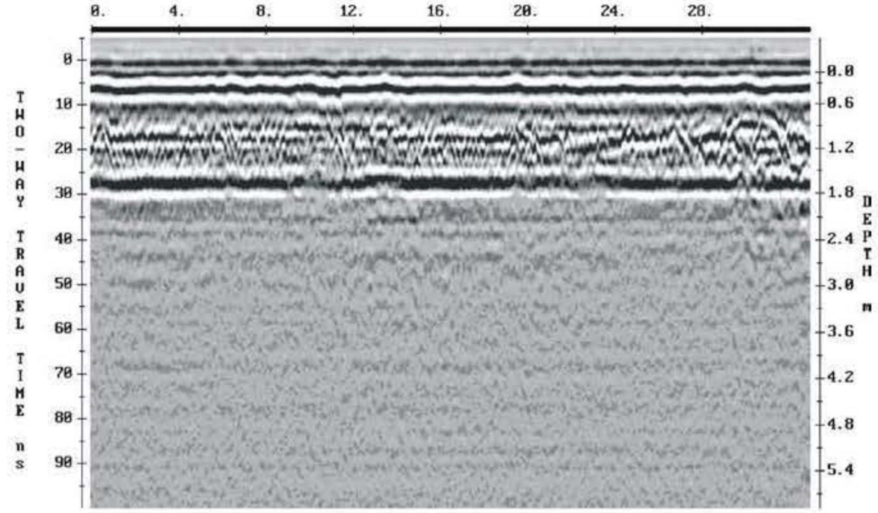

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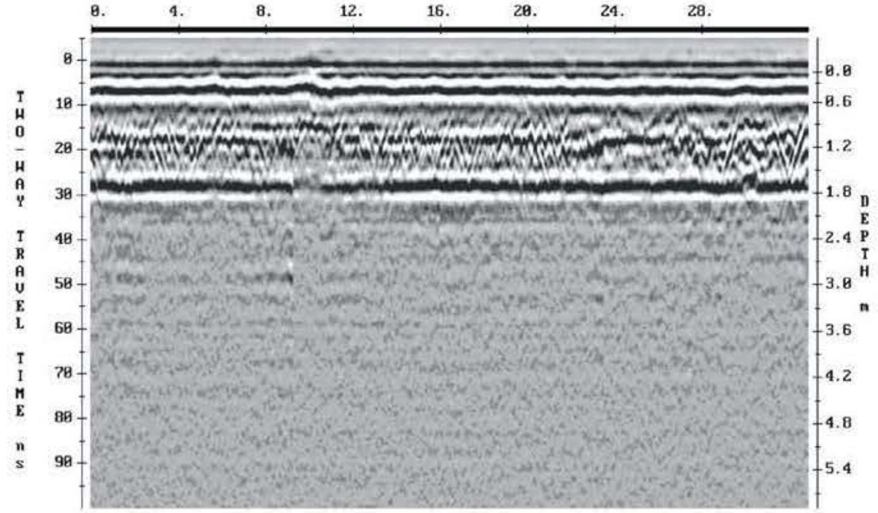

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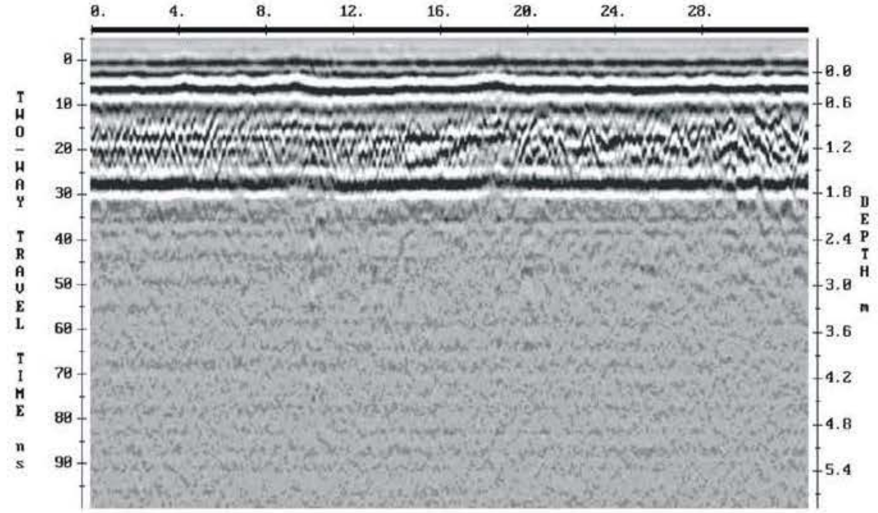

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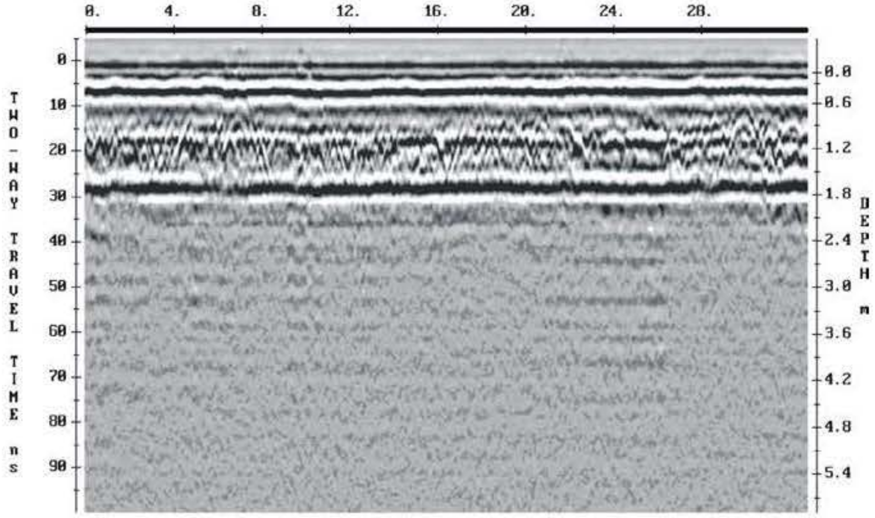

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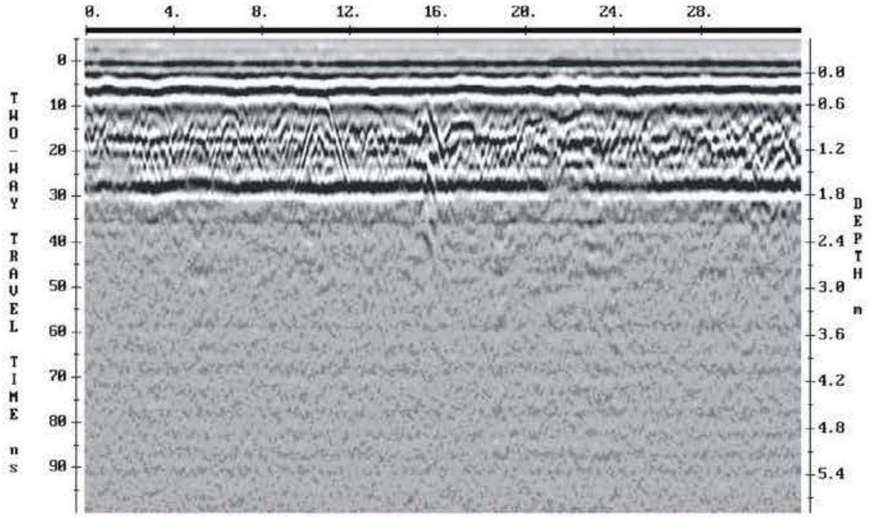

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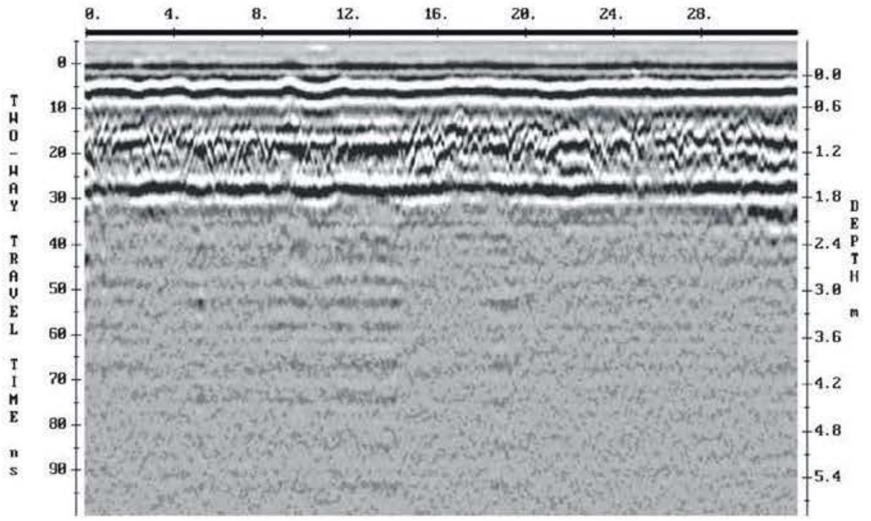

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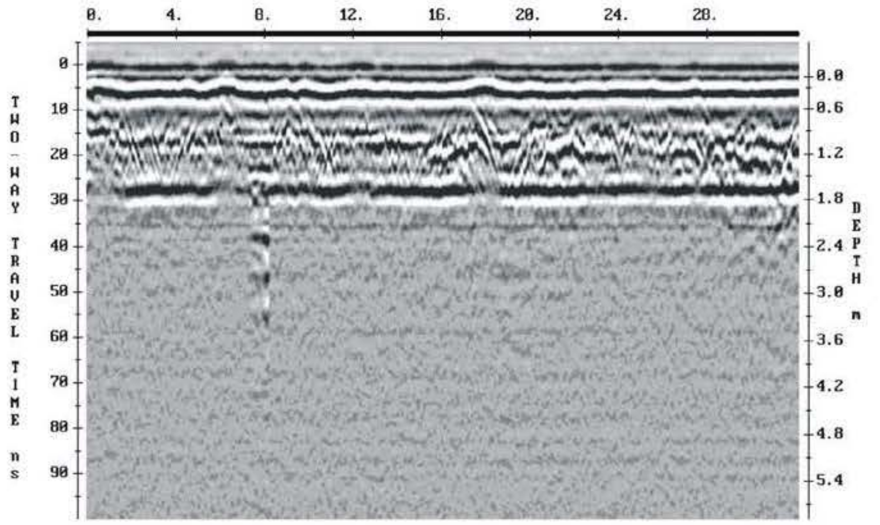

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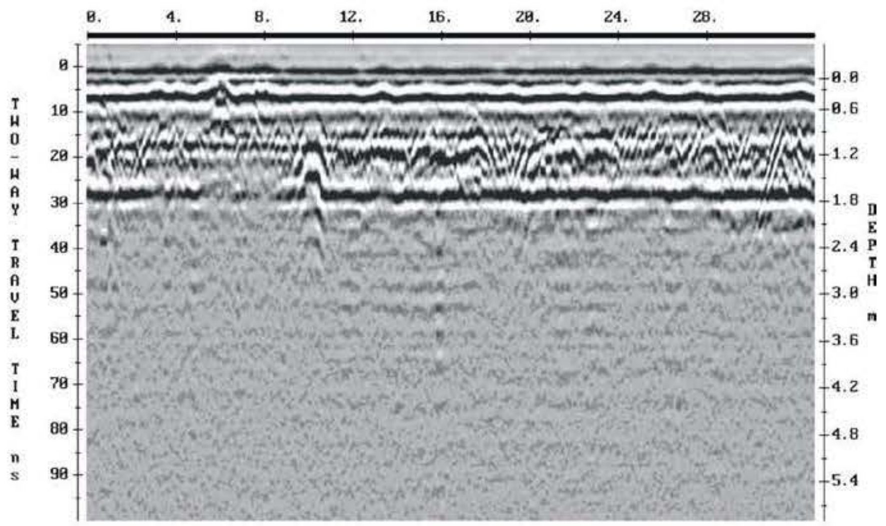

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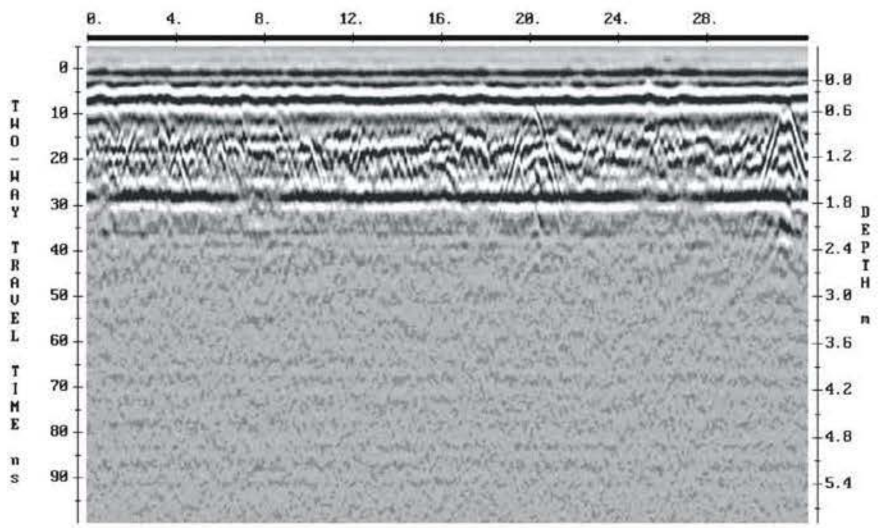
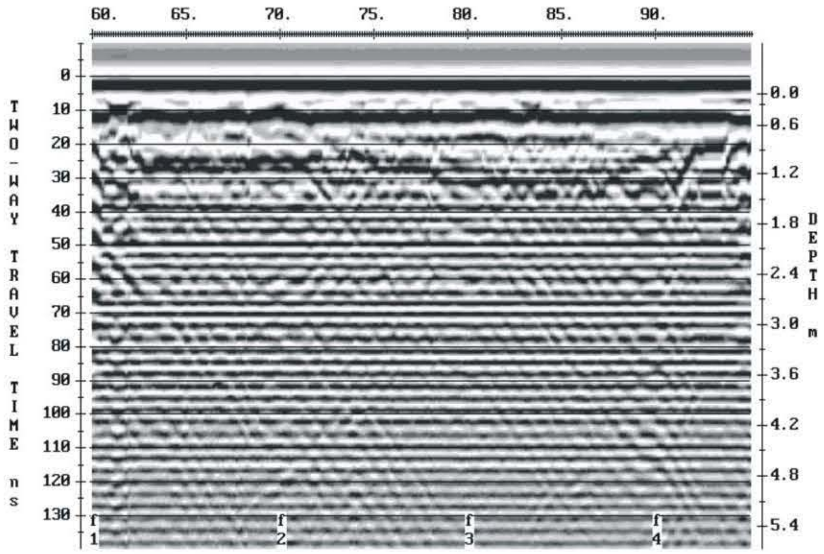


Line 42

APPENDIX IV
GPR SURVEYS
(part 3 of 3)

KOUKOURARATA
Lower survey grid
200 MHz Frequency



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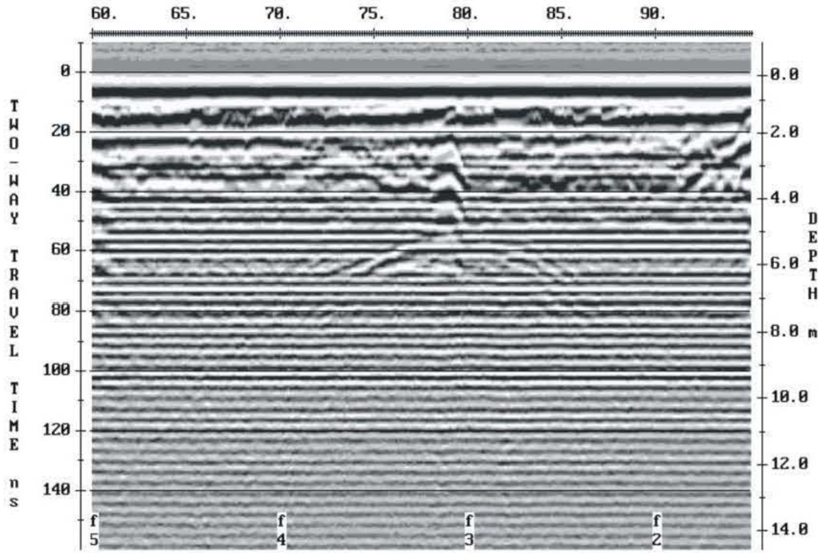

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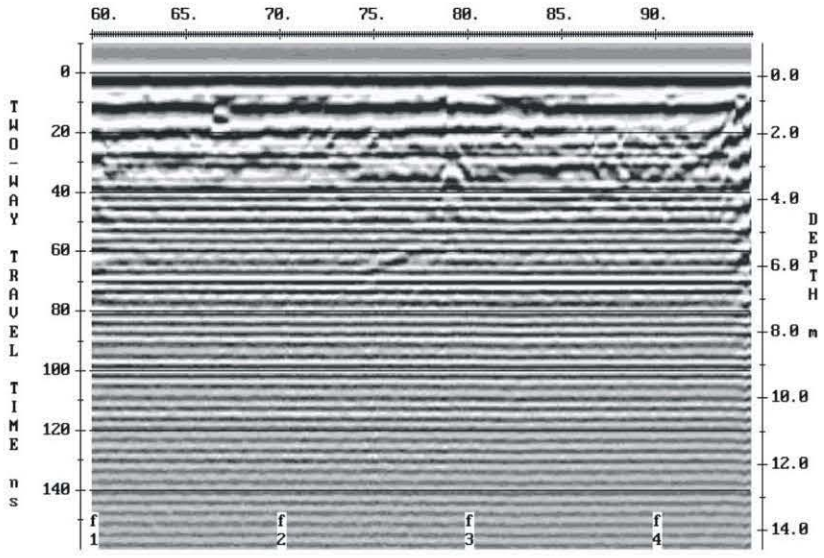

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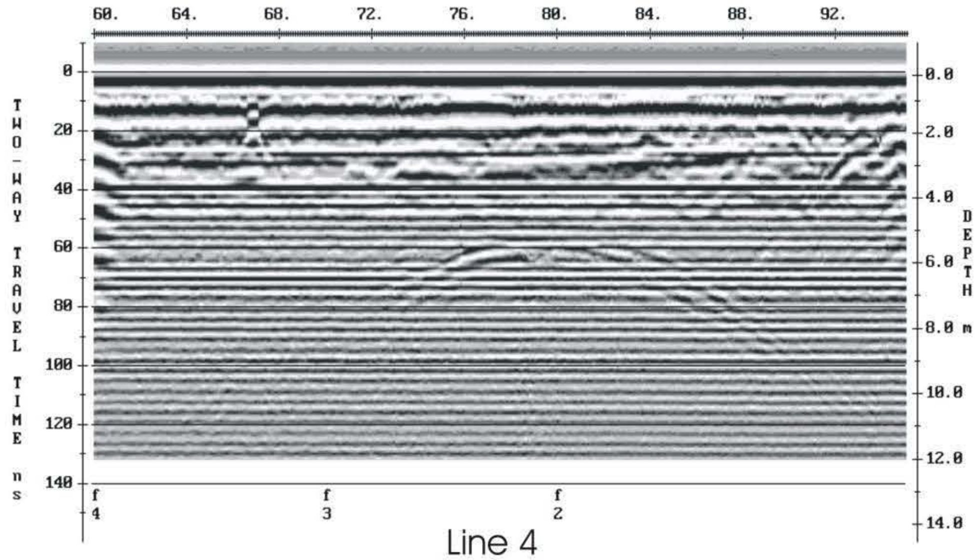

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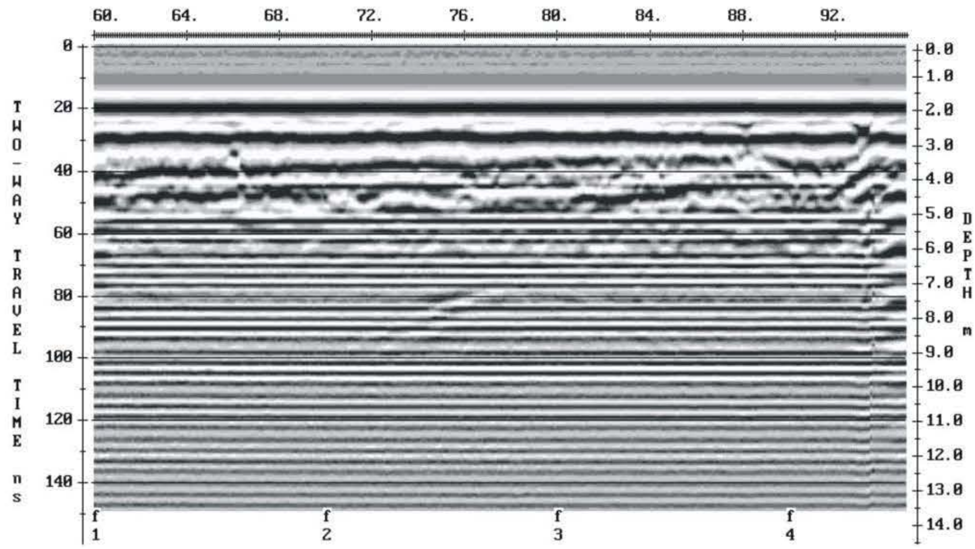

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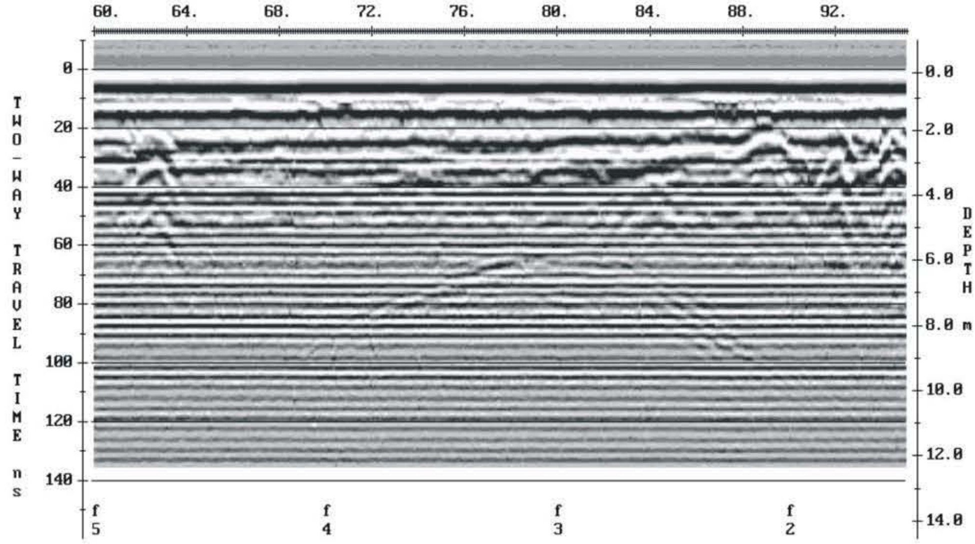

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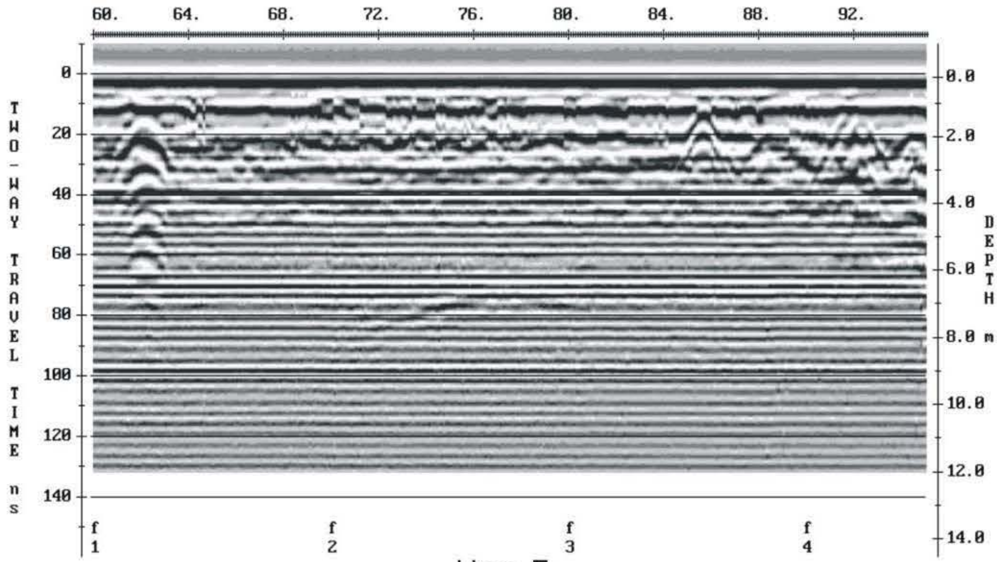

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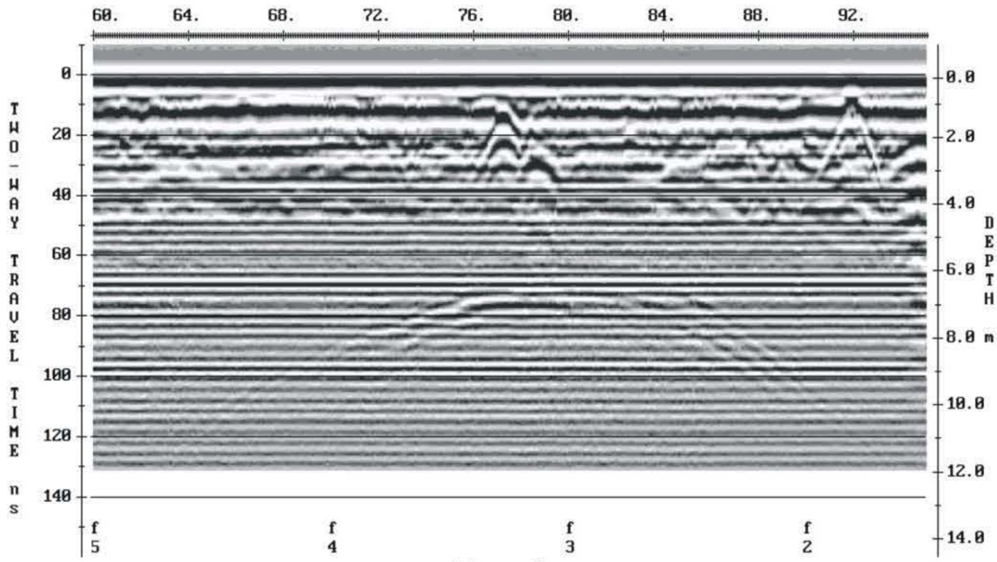

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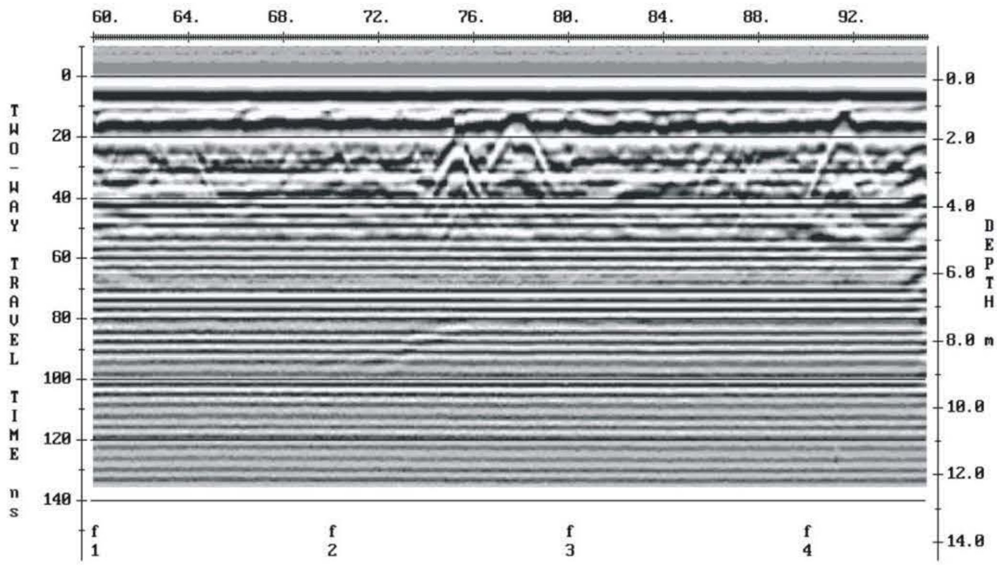

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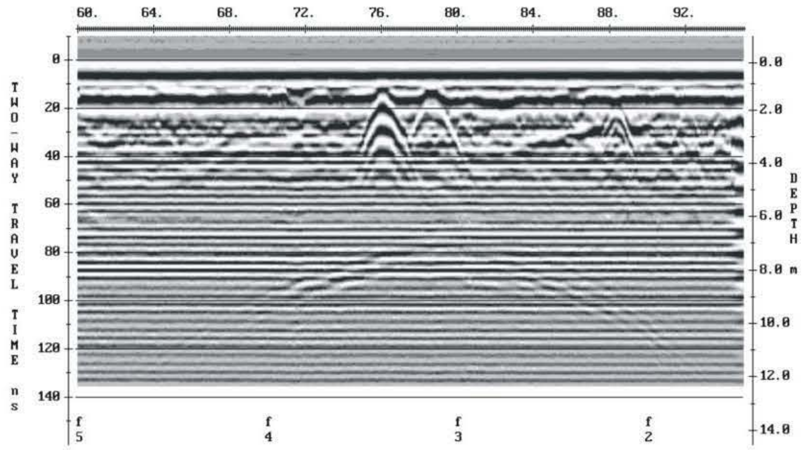

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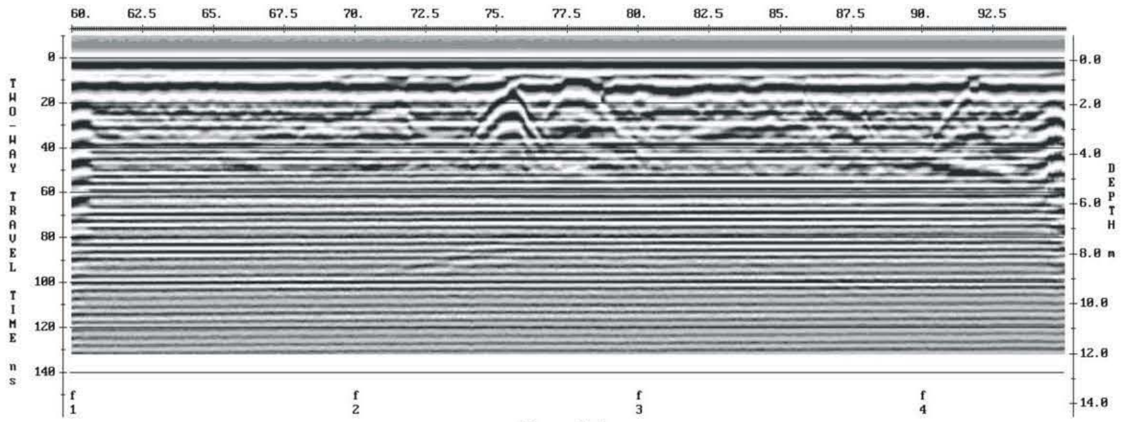

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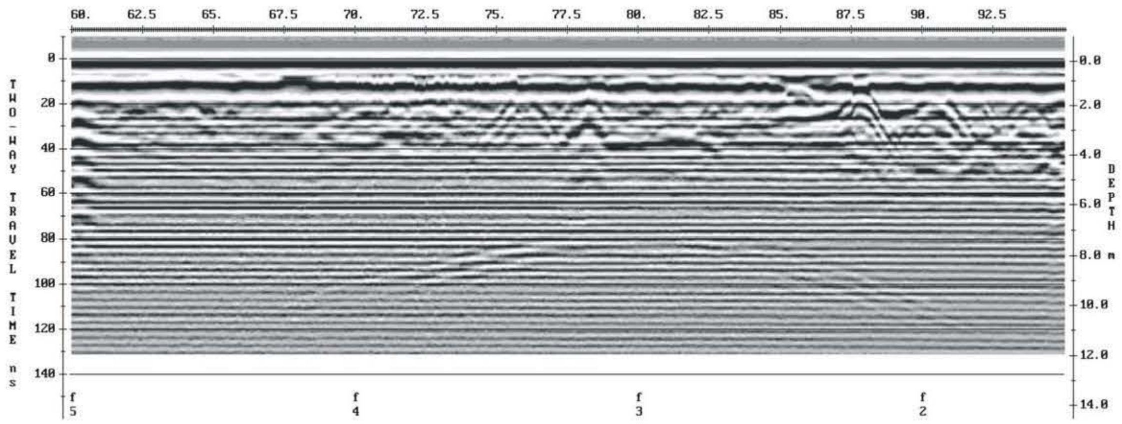

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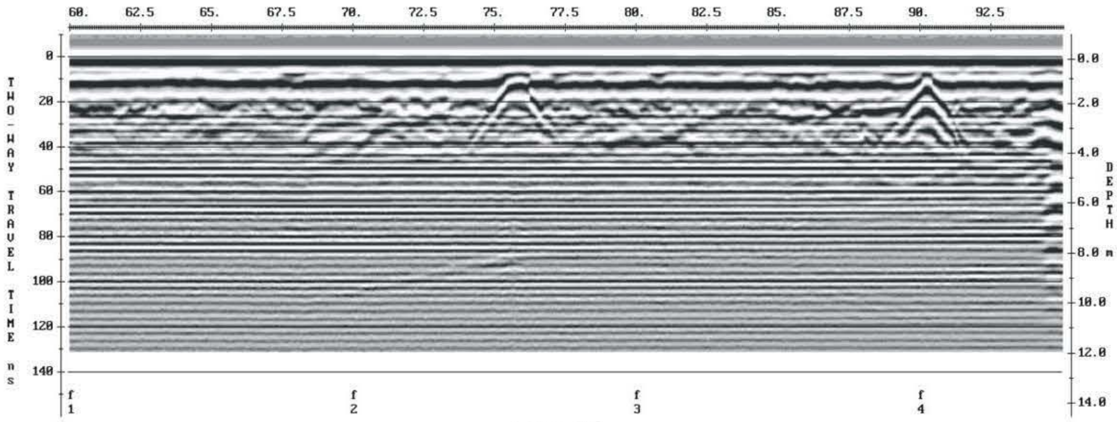

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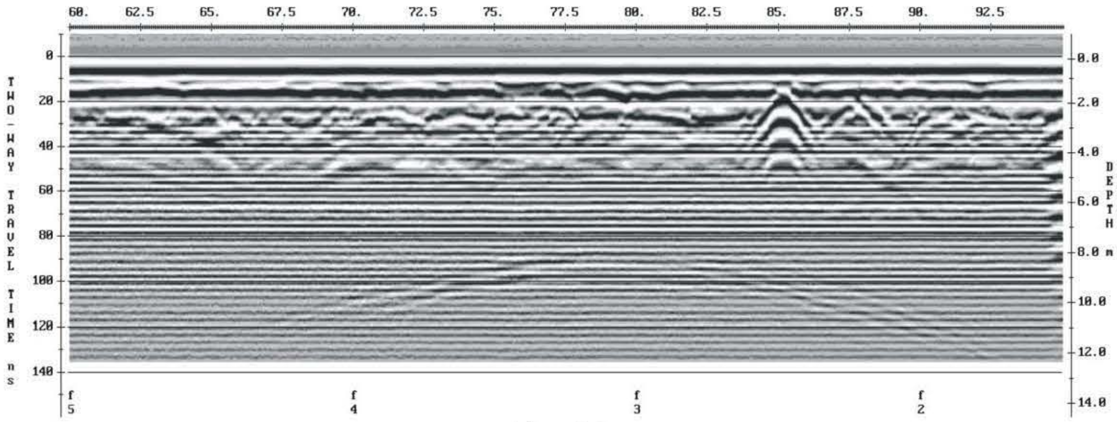

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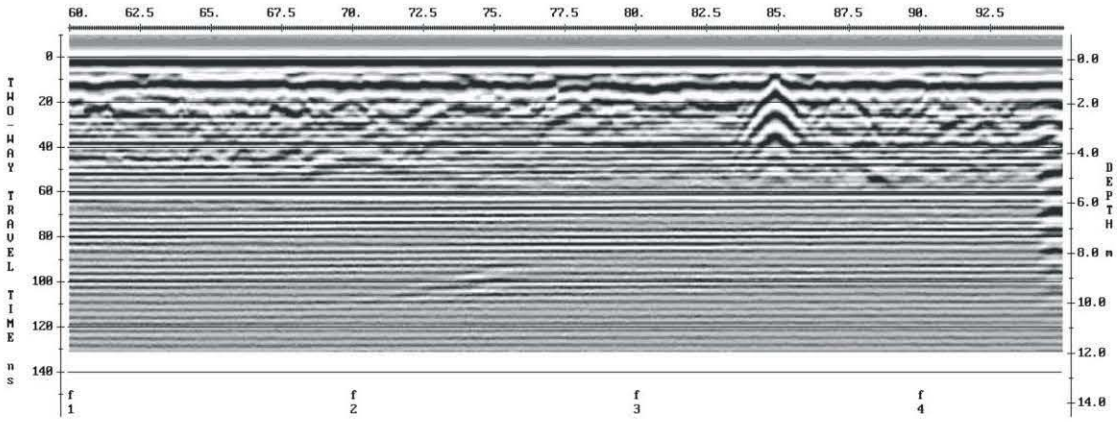

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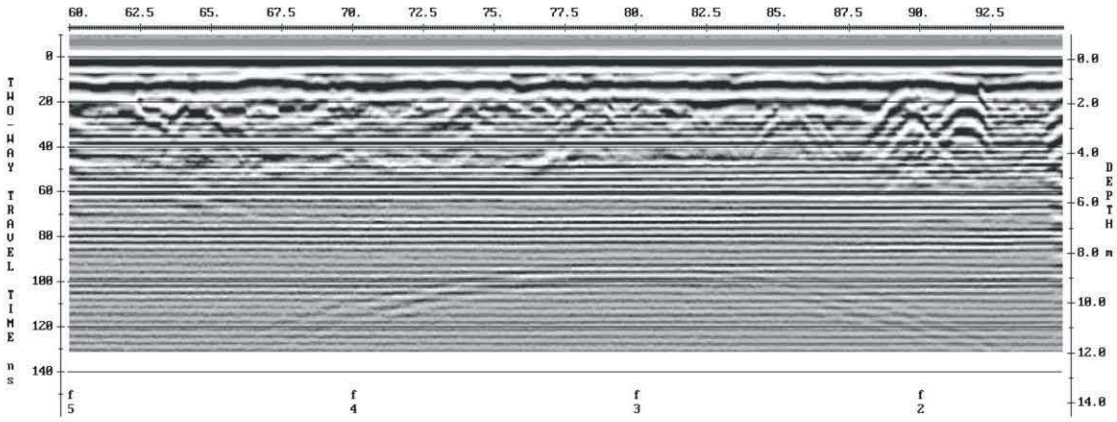

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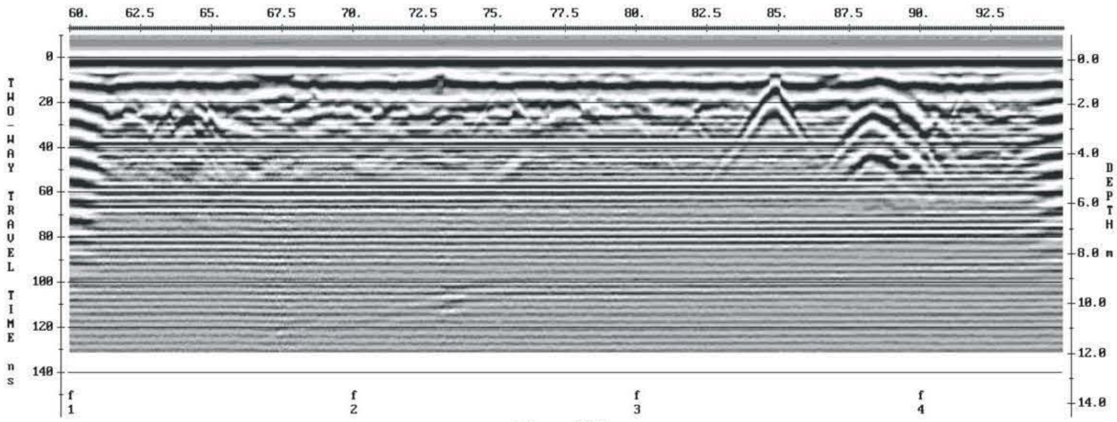

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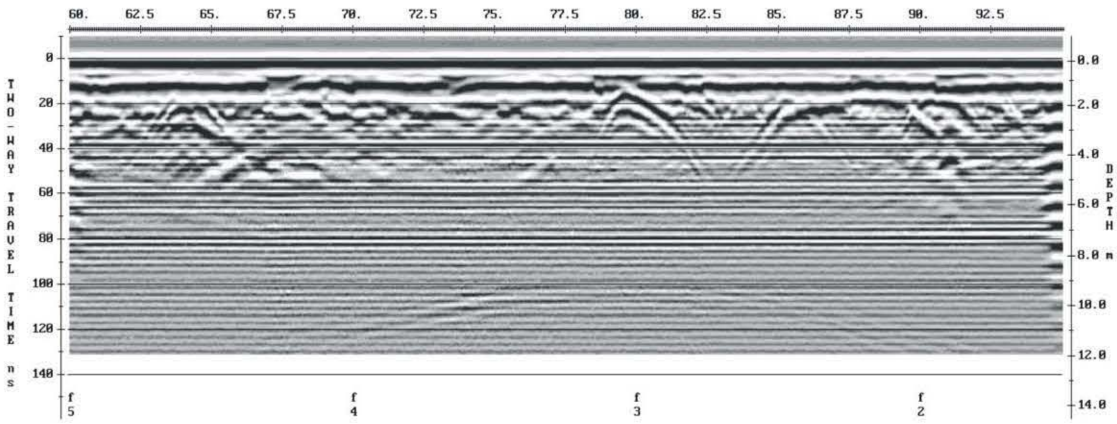

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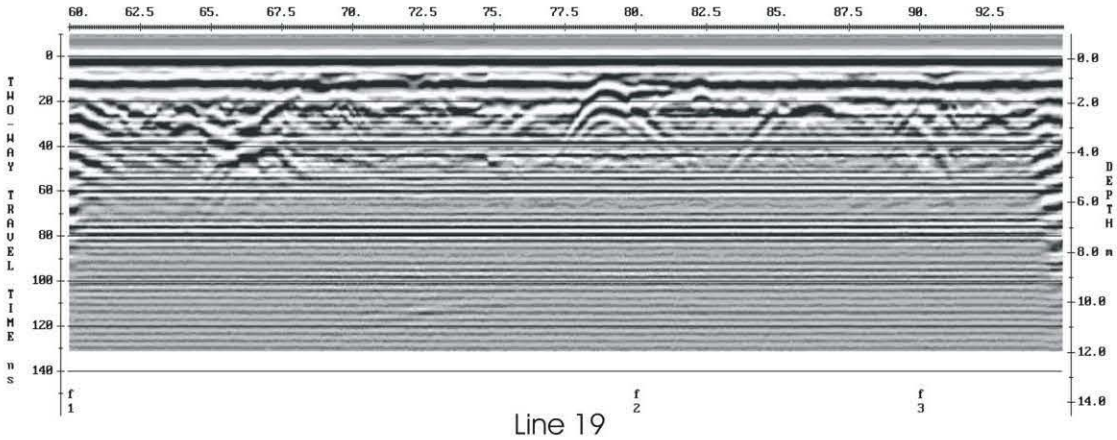

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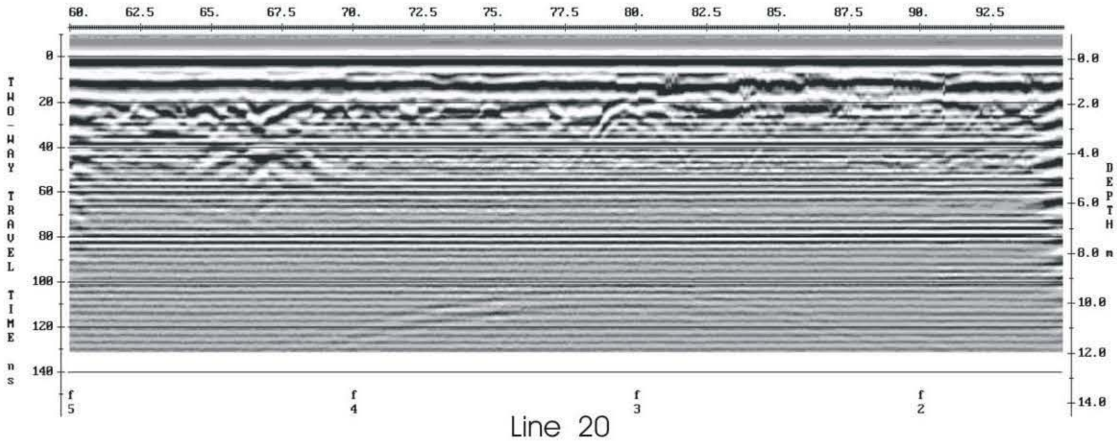

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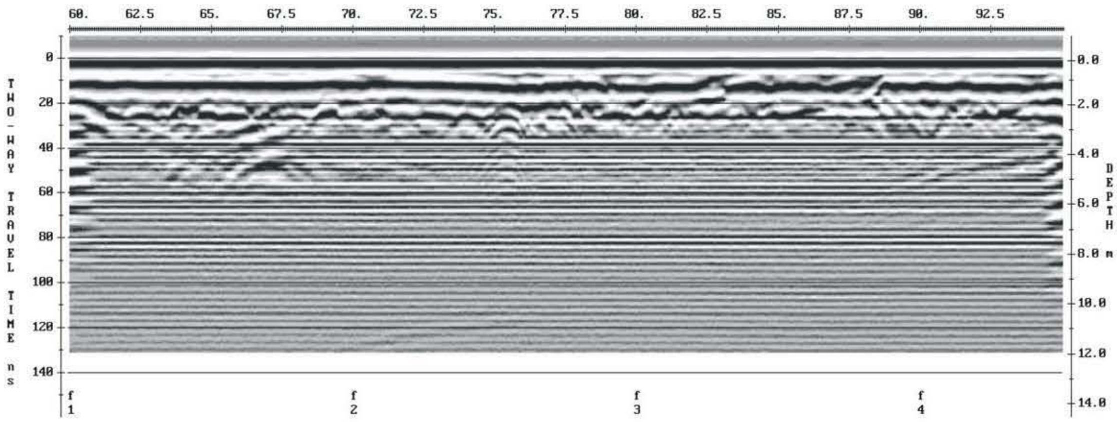

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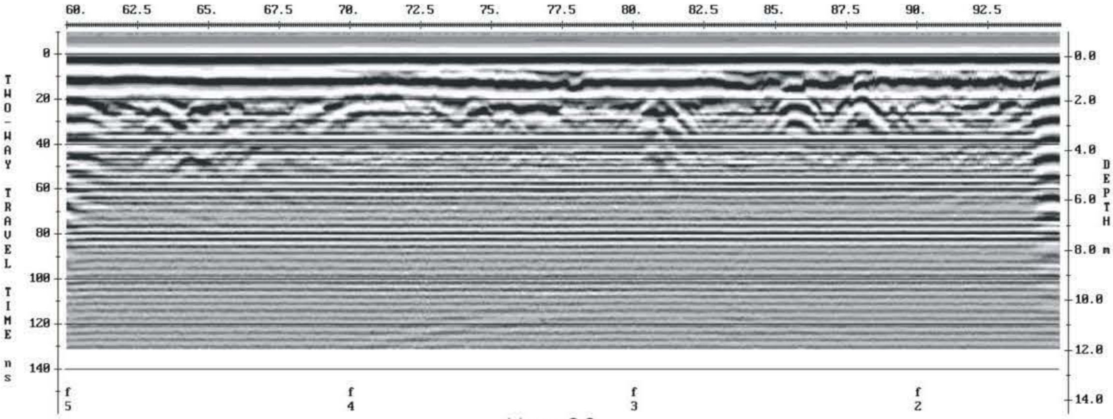

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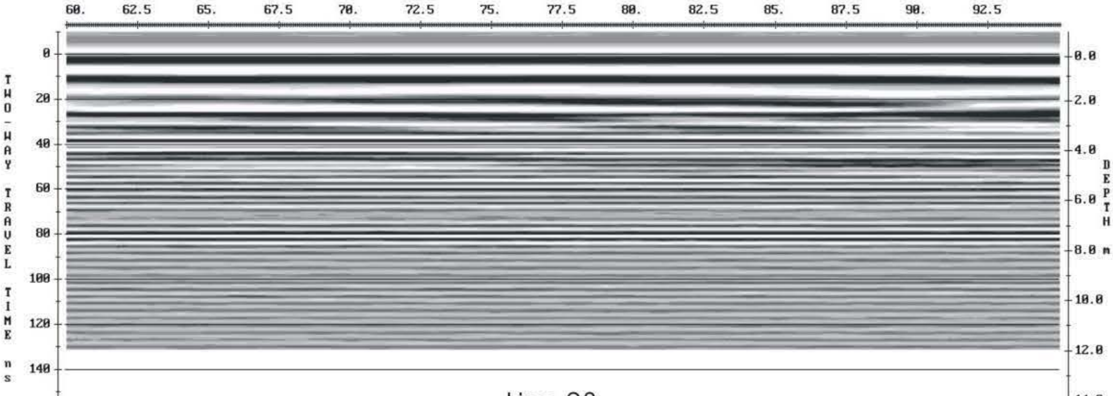

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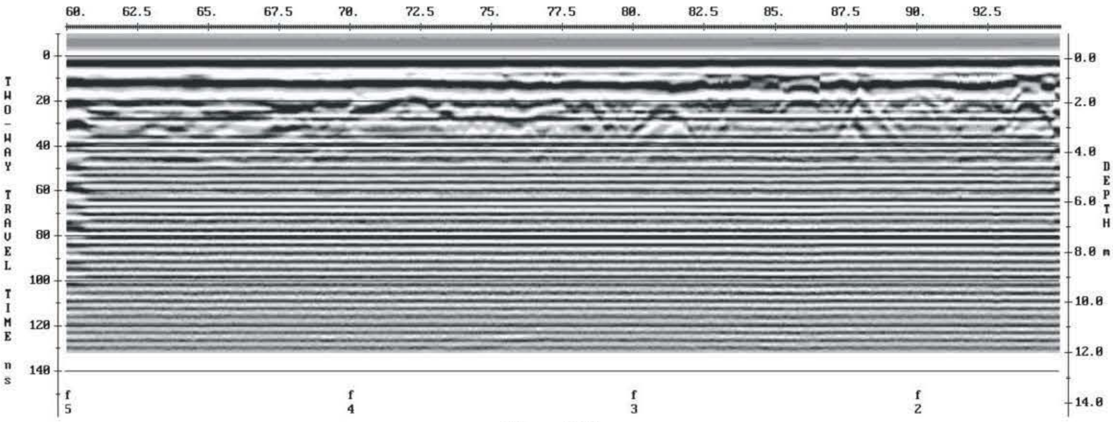

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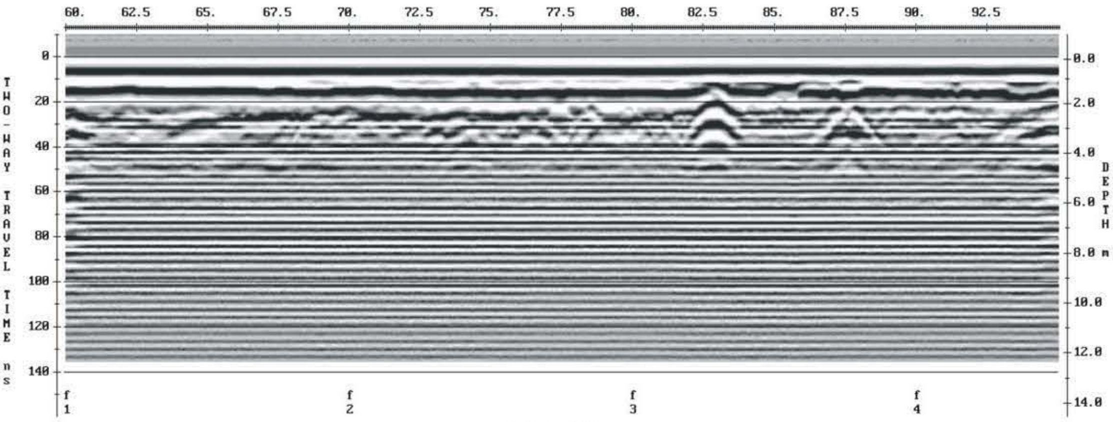

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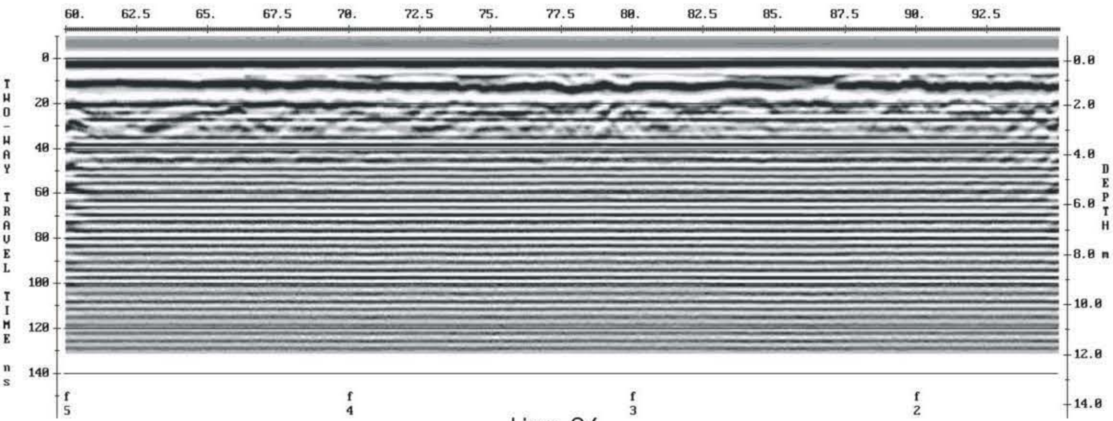

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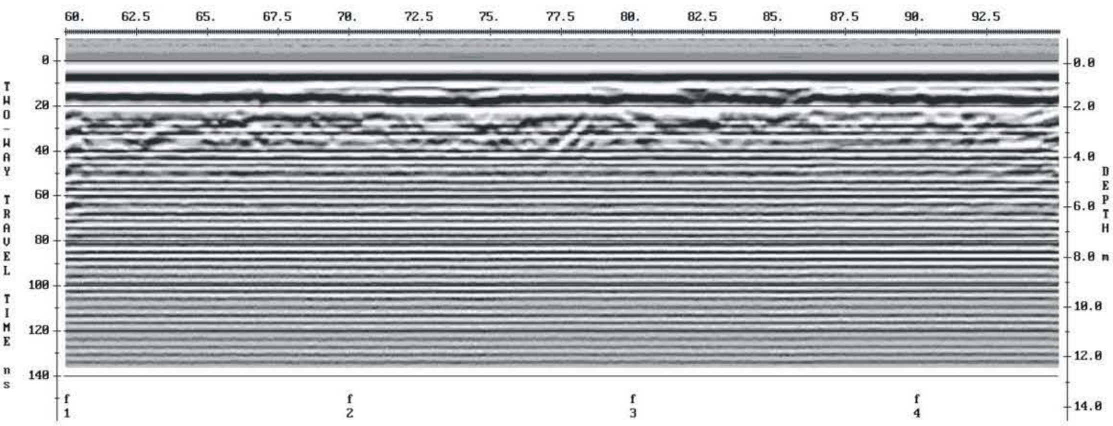

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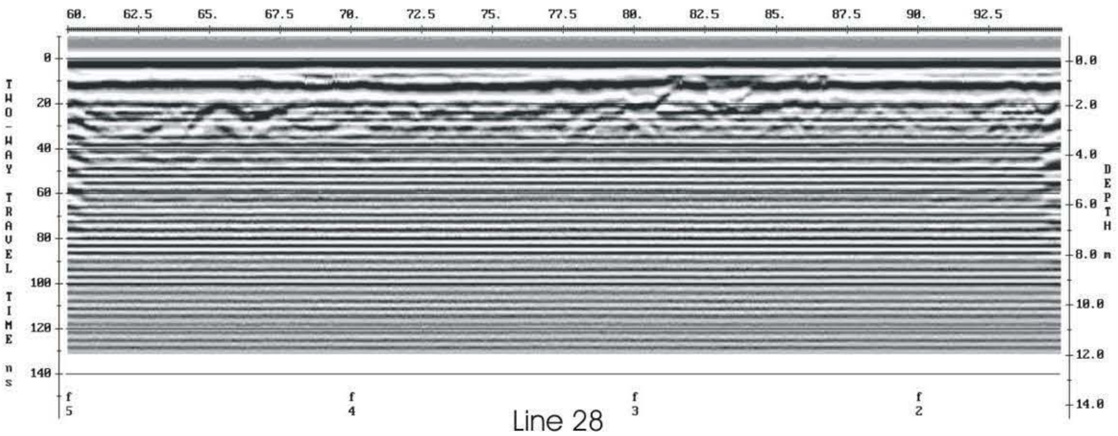

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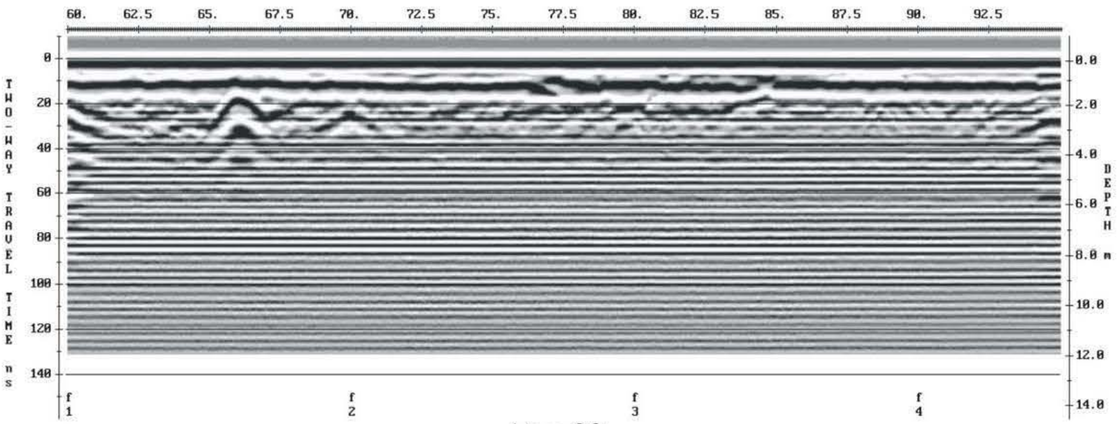

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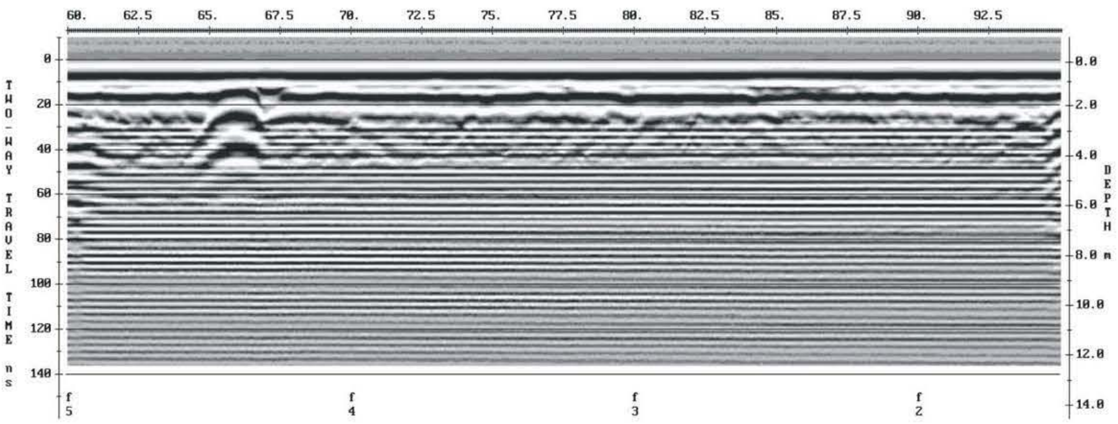

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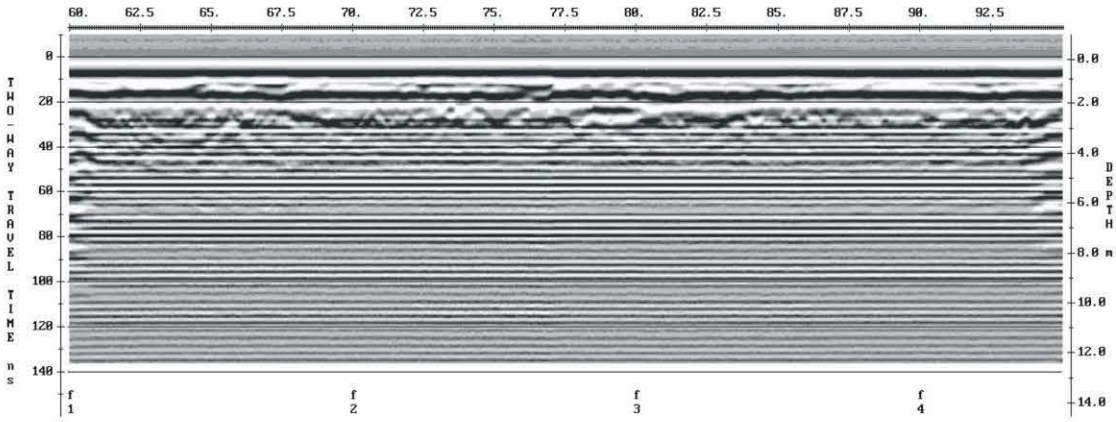

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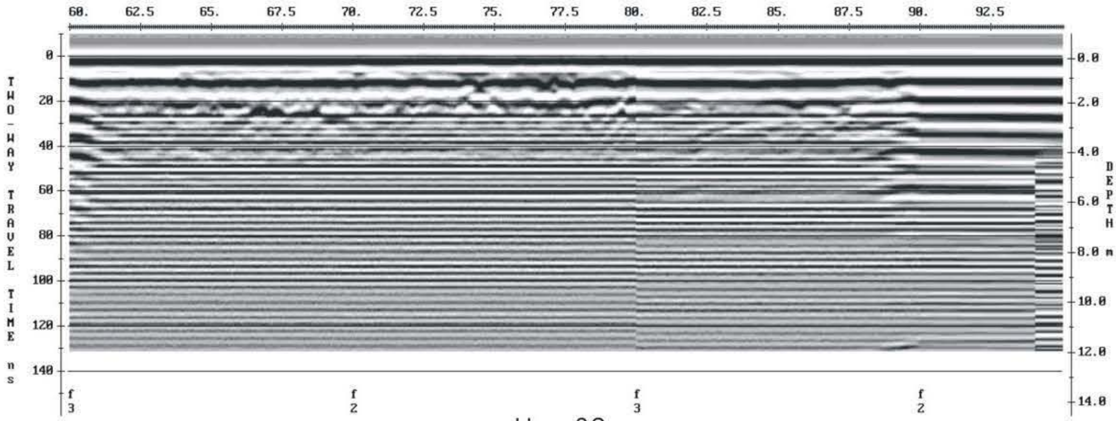

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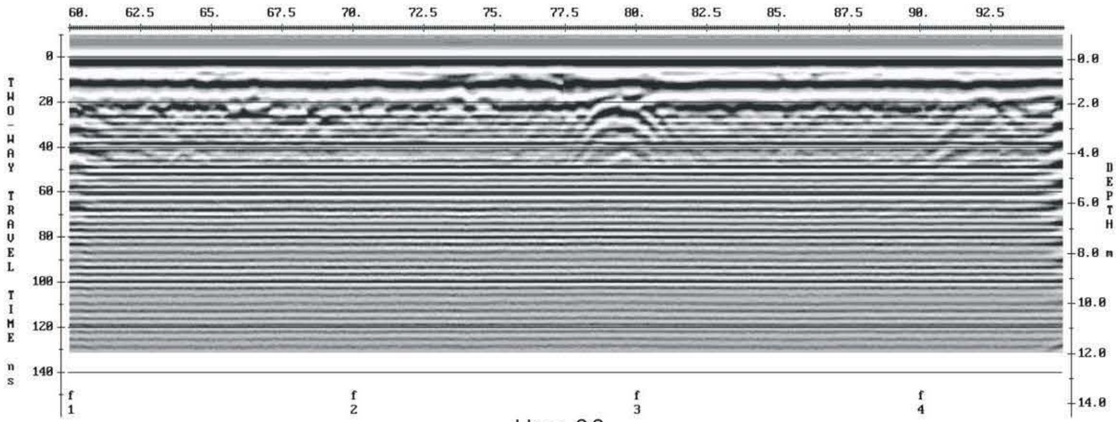

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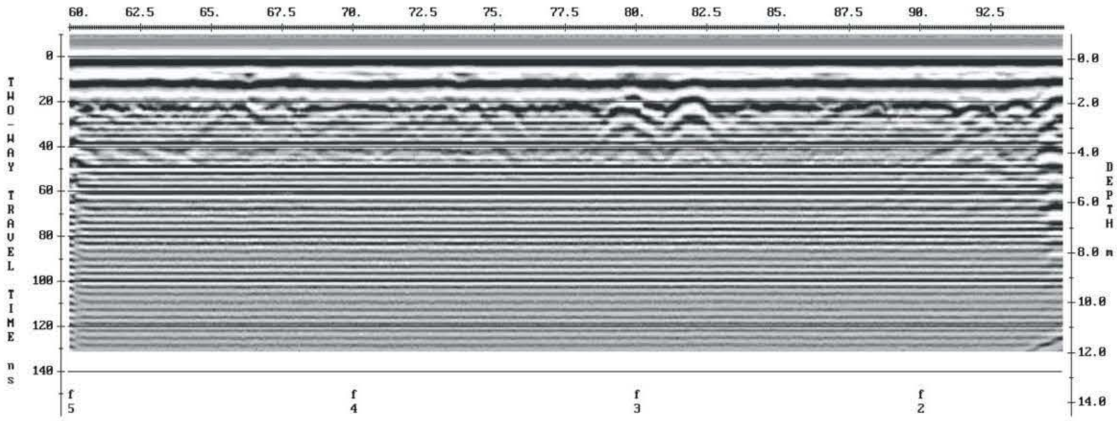

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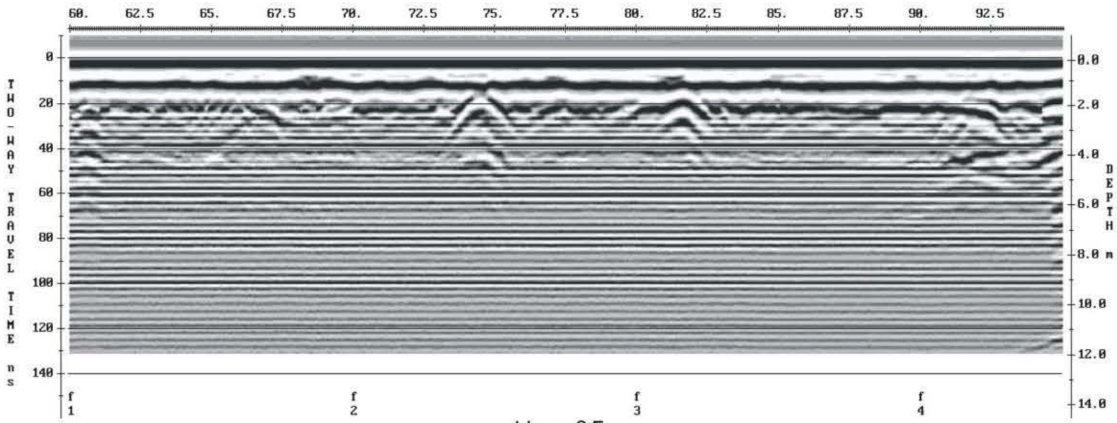

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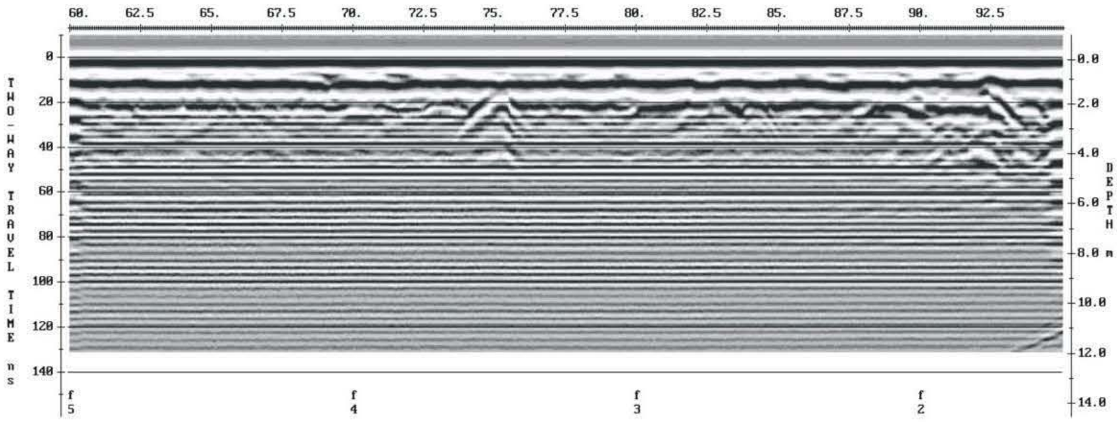

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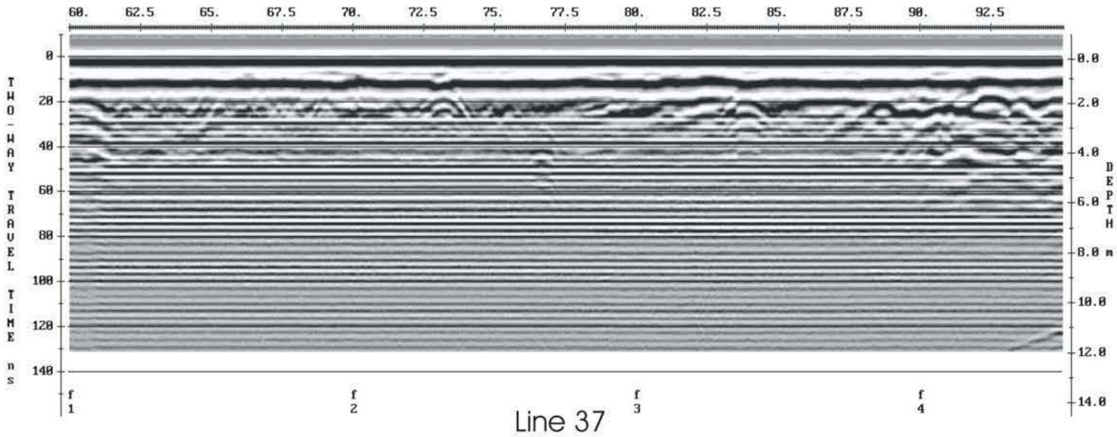

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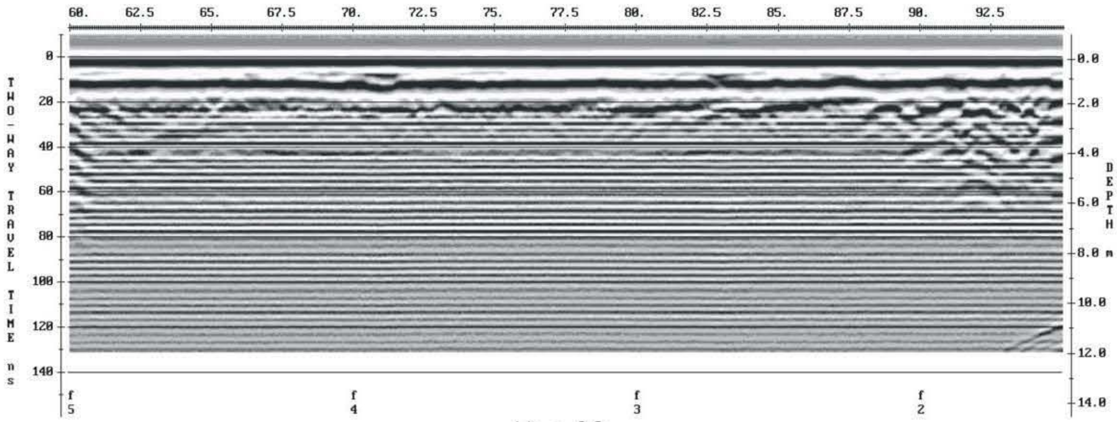

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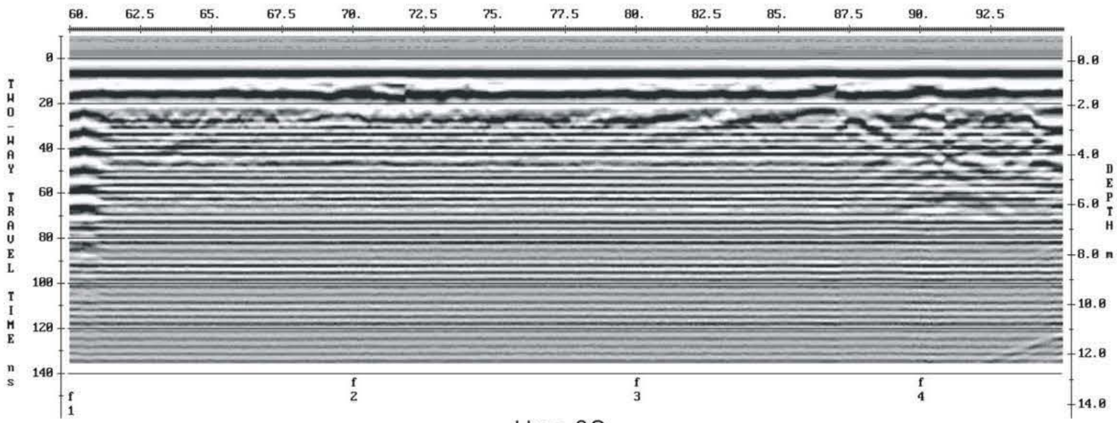

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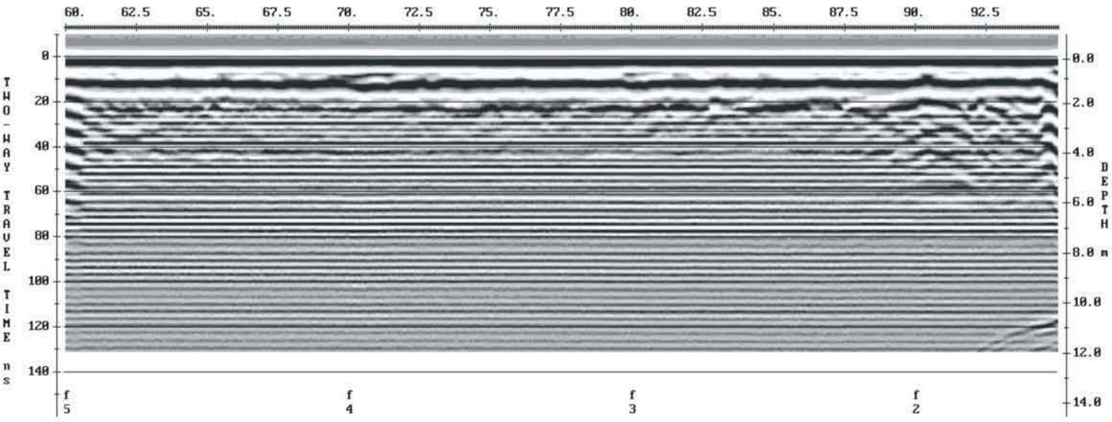

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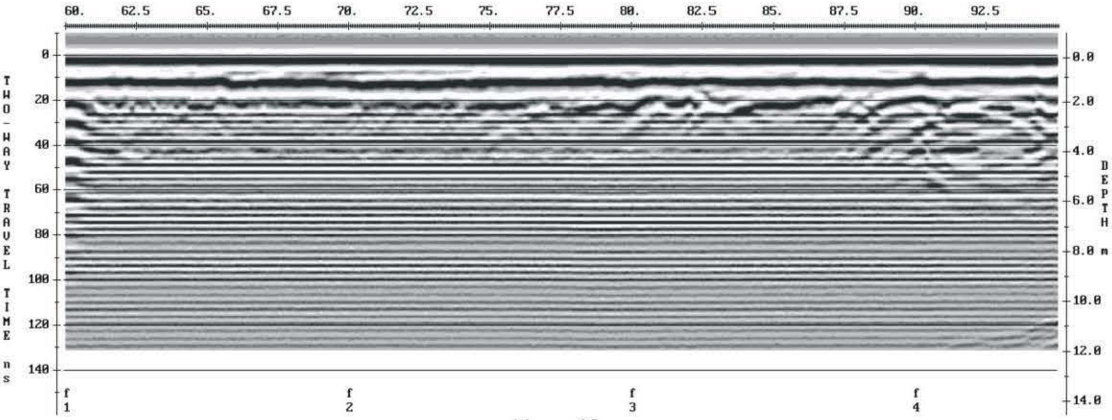

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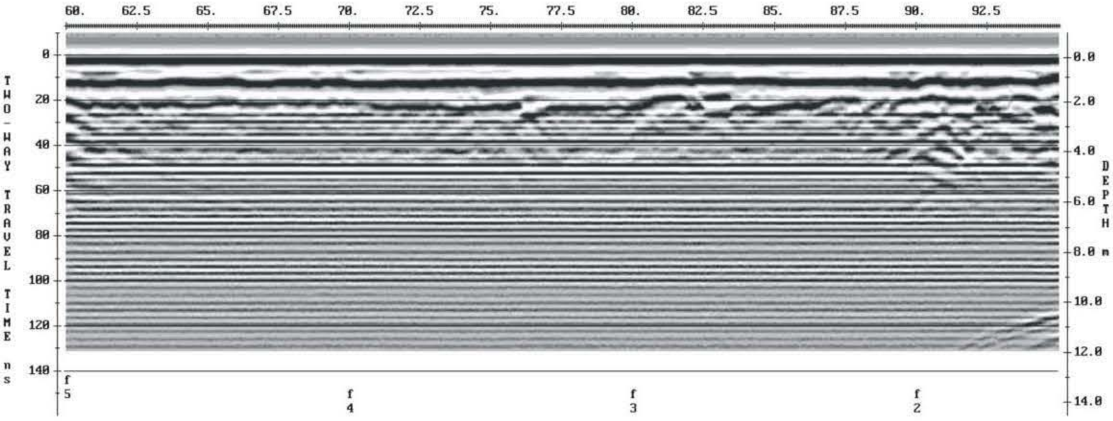

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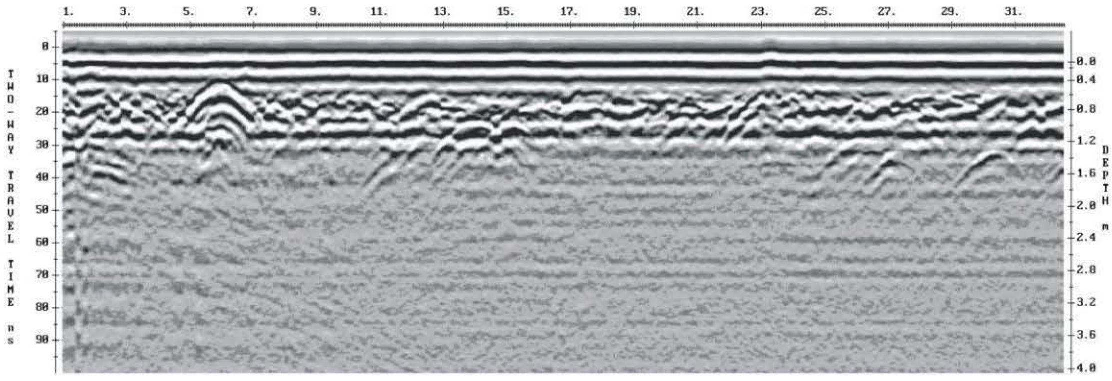
APPENDIX V
GPR SURVEYS
(part 1 of 2)

WAIREWA
Lower survey grid
225 MHz Frequency



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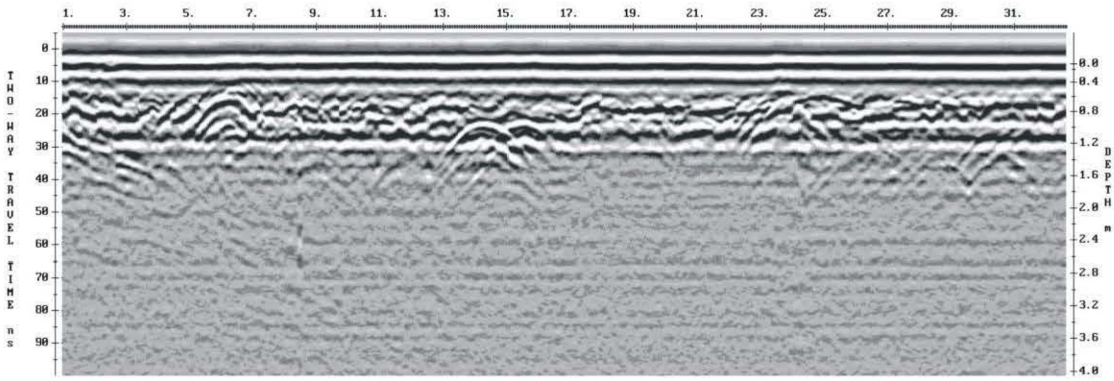

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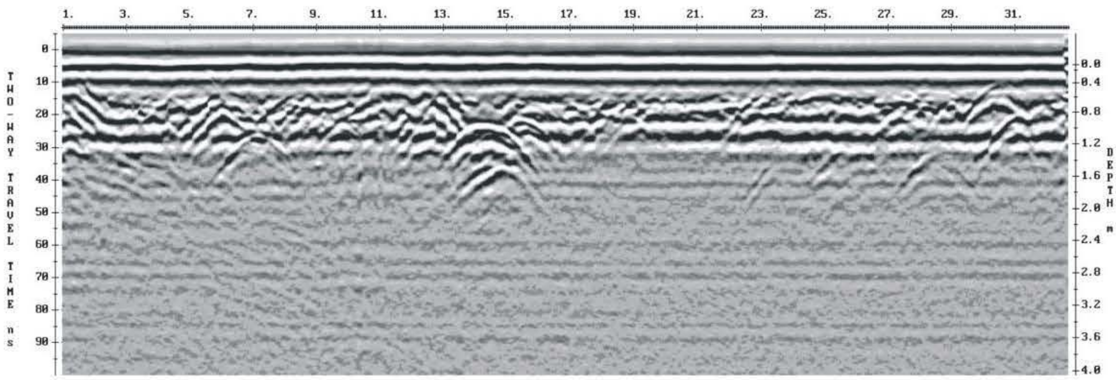

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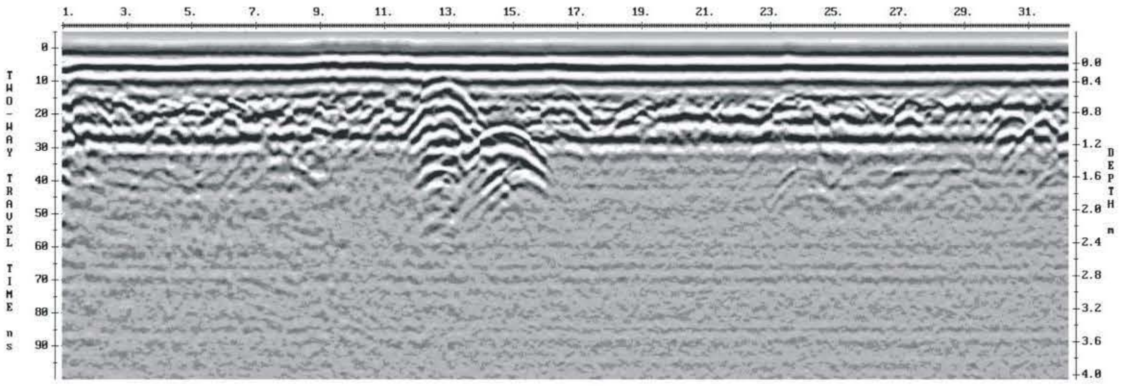

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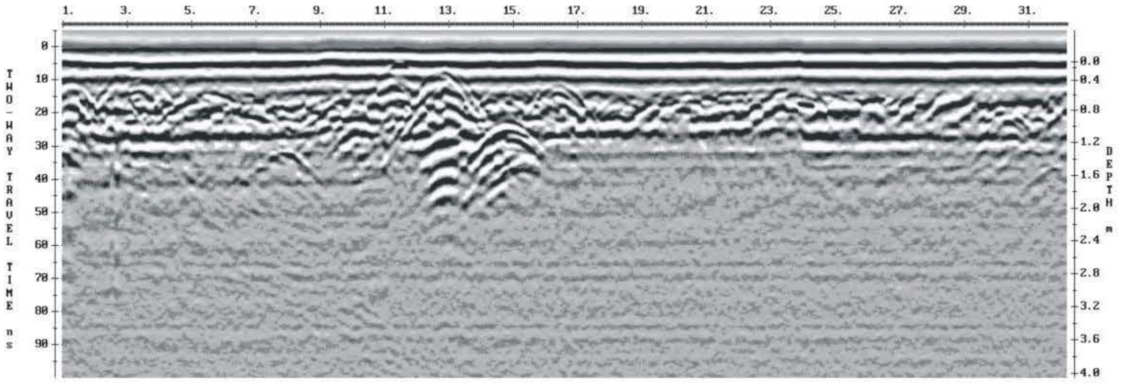

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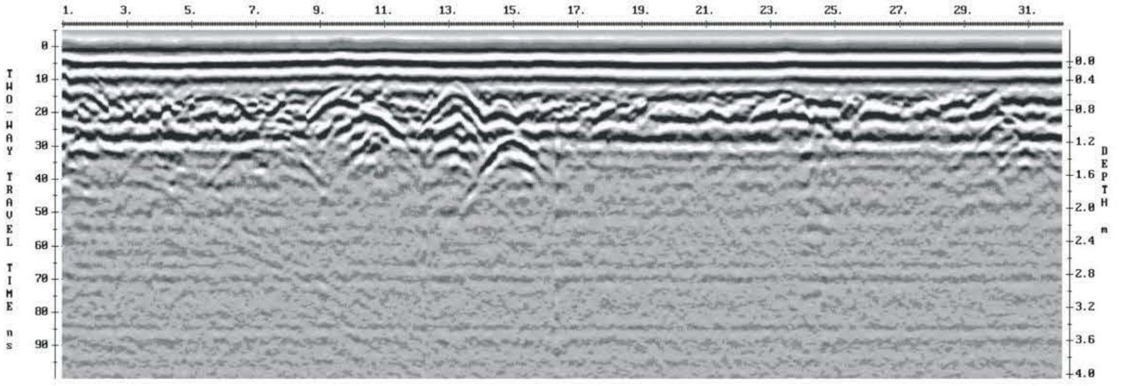

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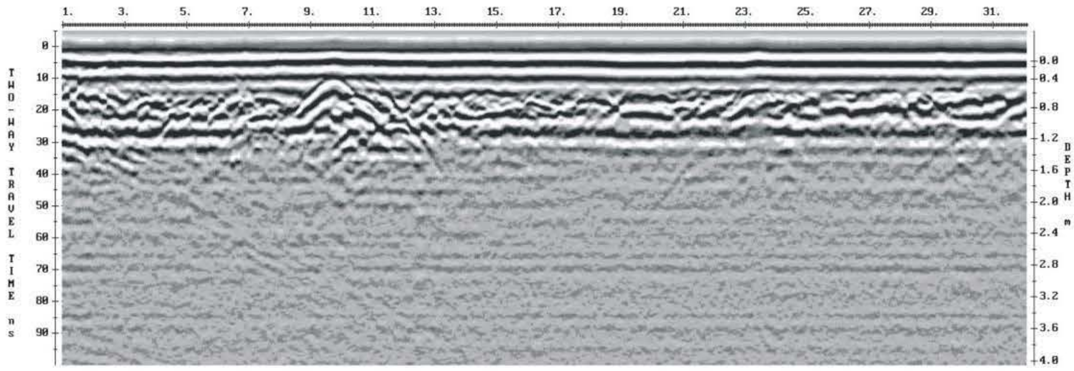

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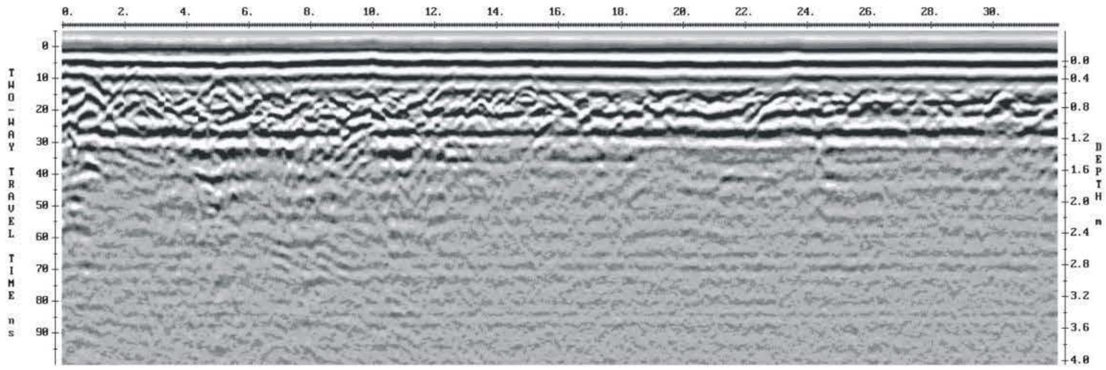

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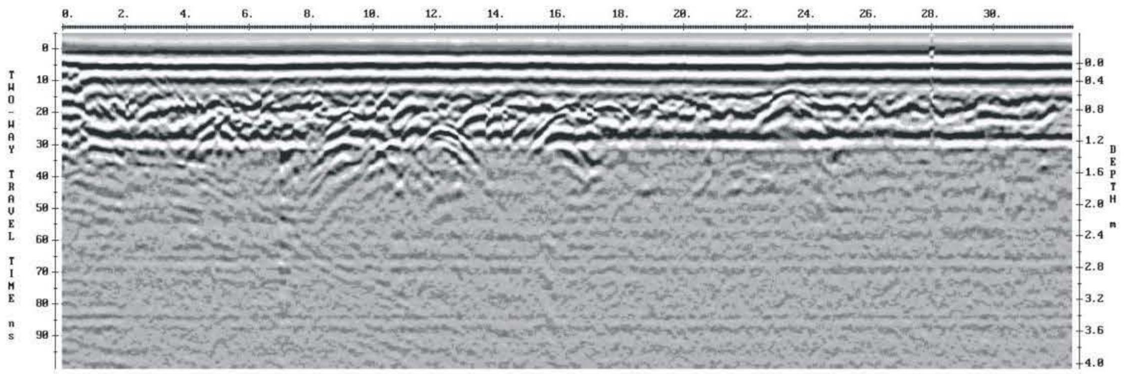

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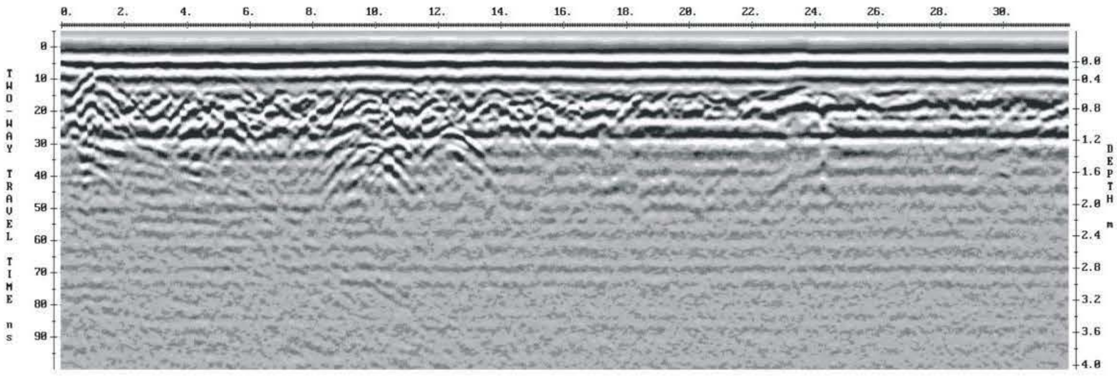

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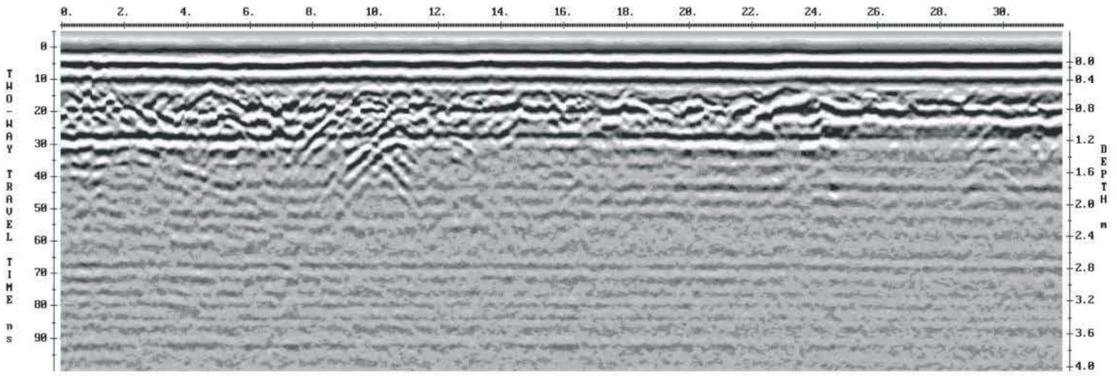

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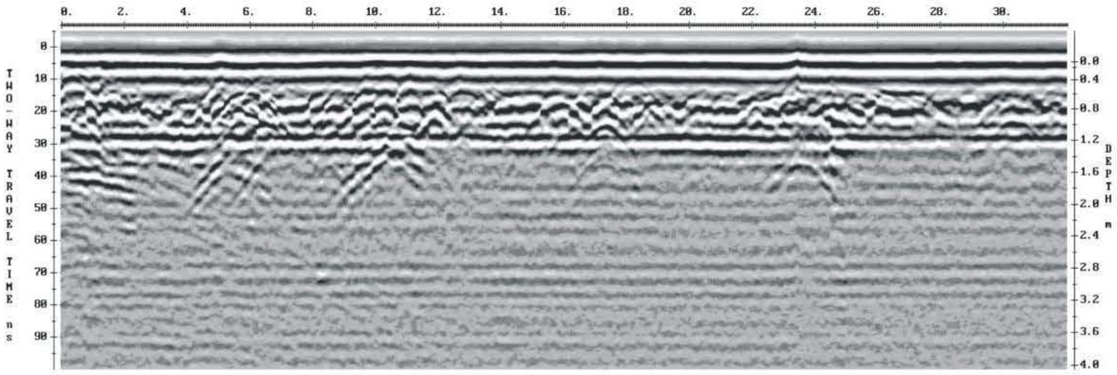

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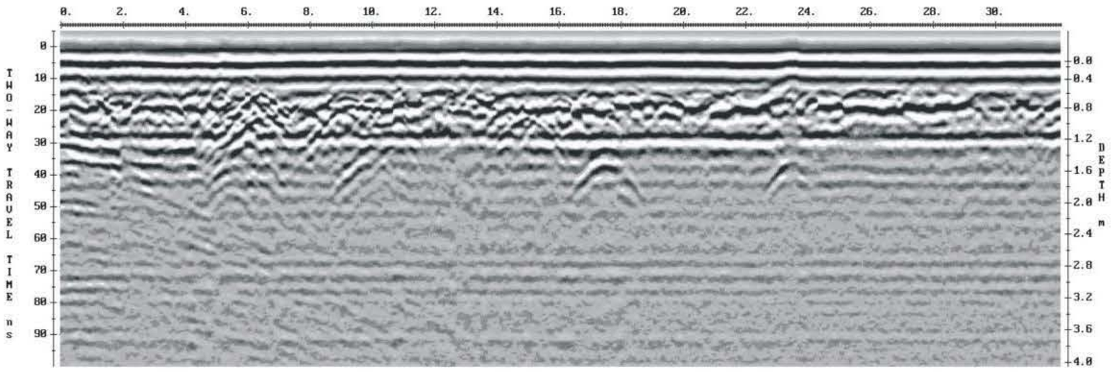

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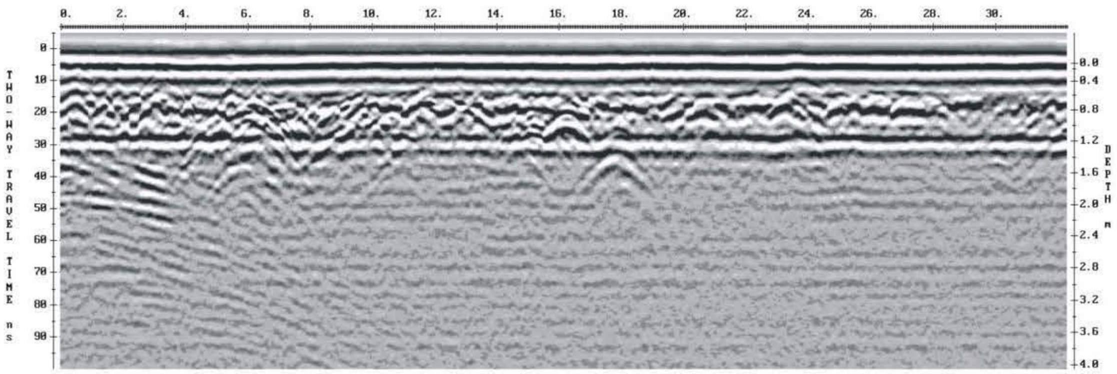

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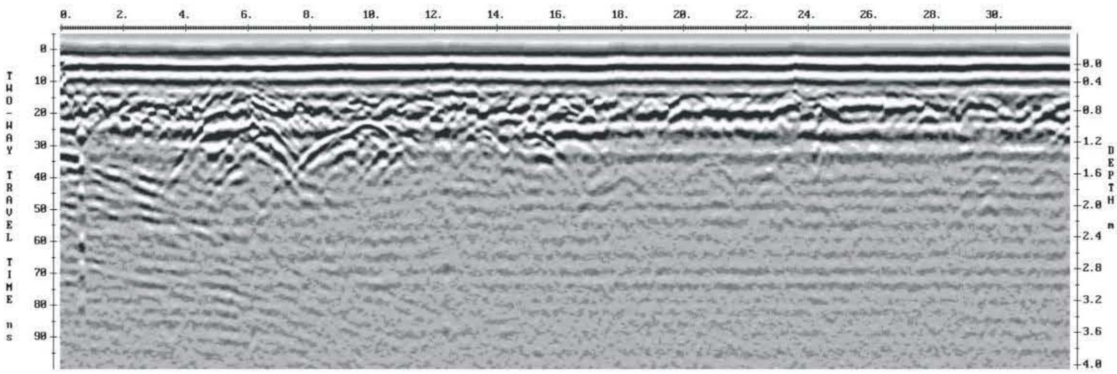

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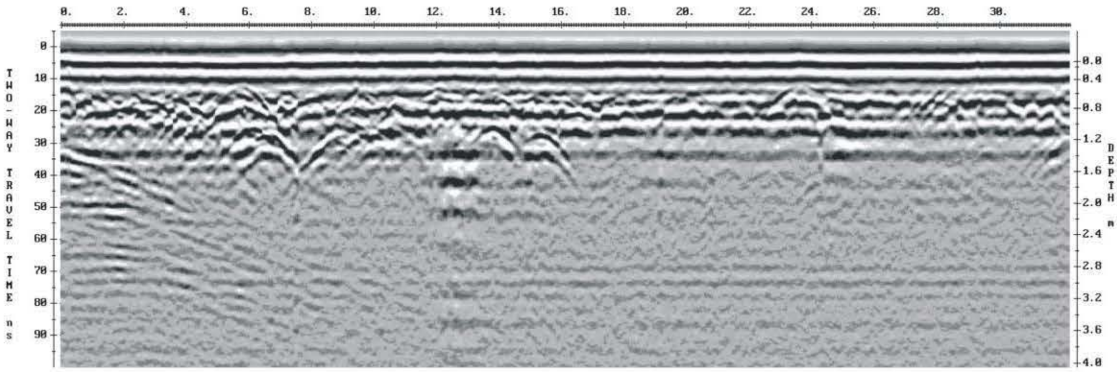

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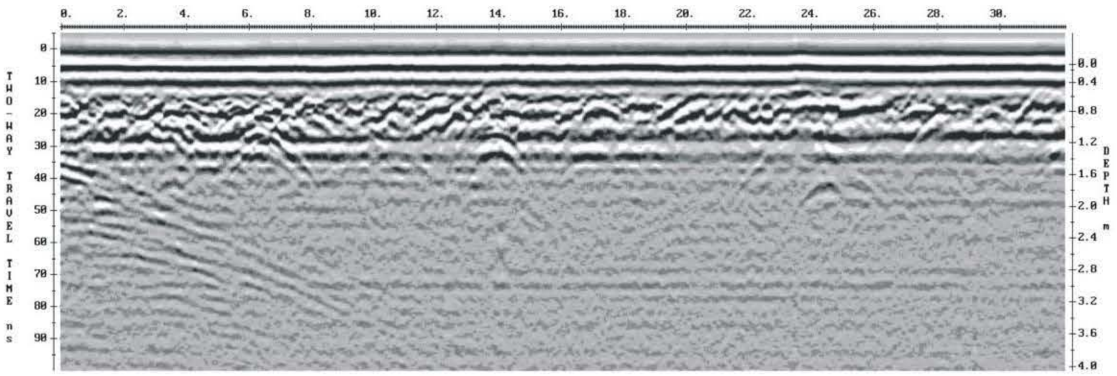

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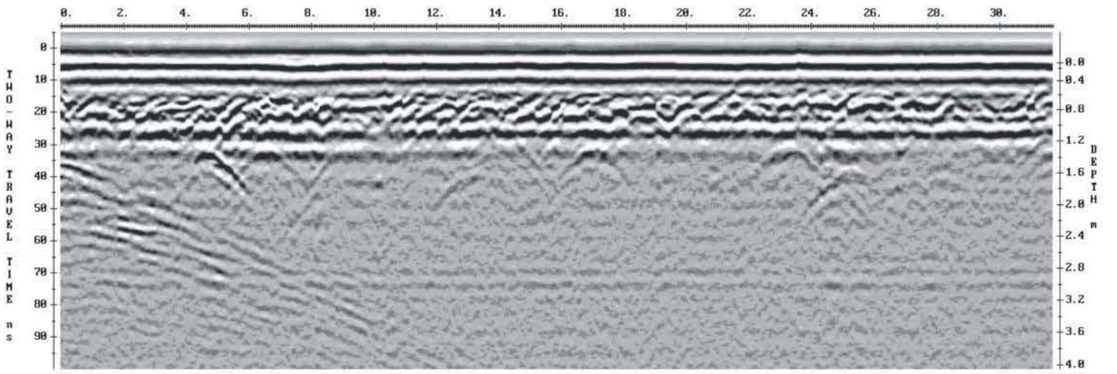

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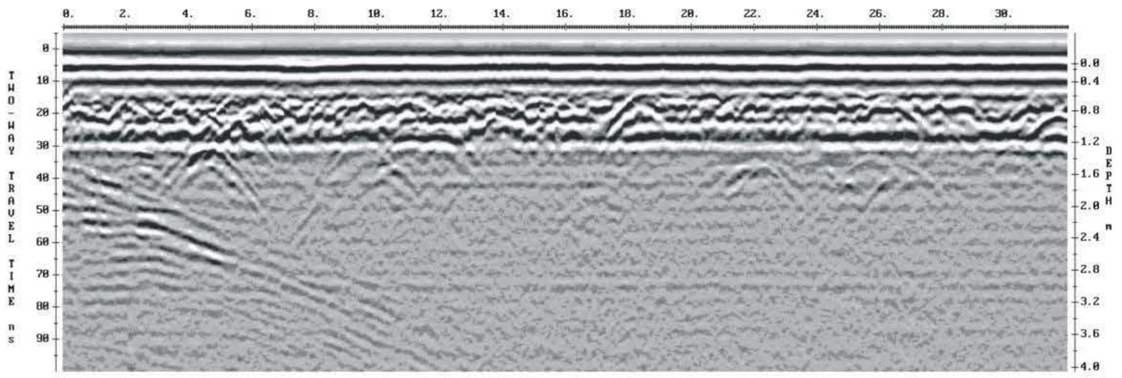

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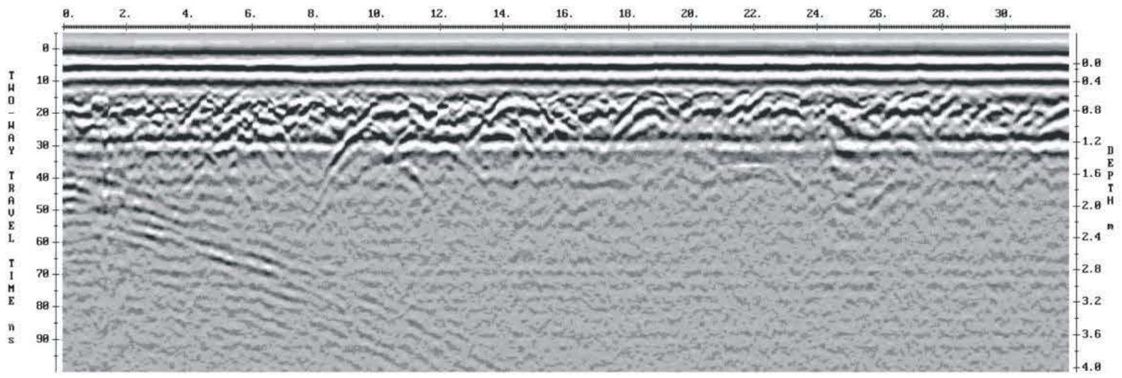

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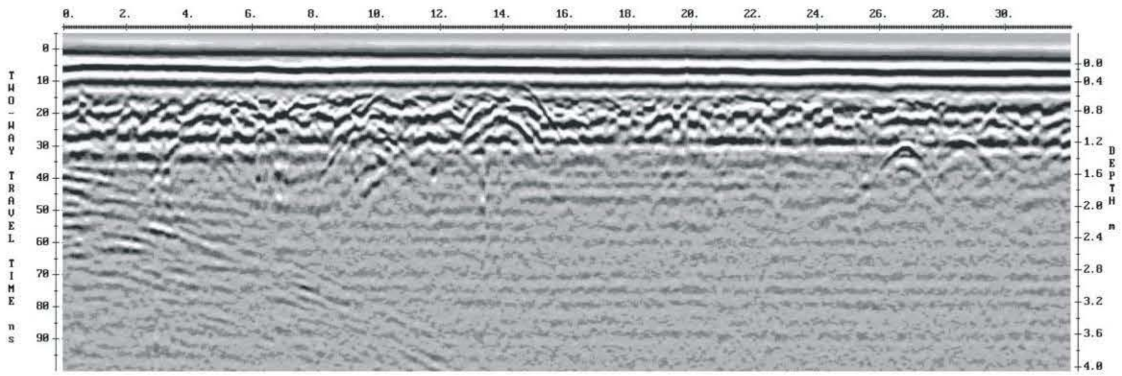

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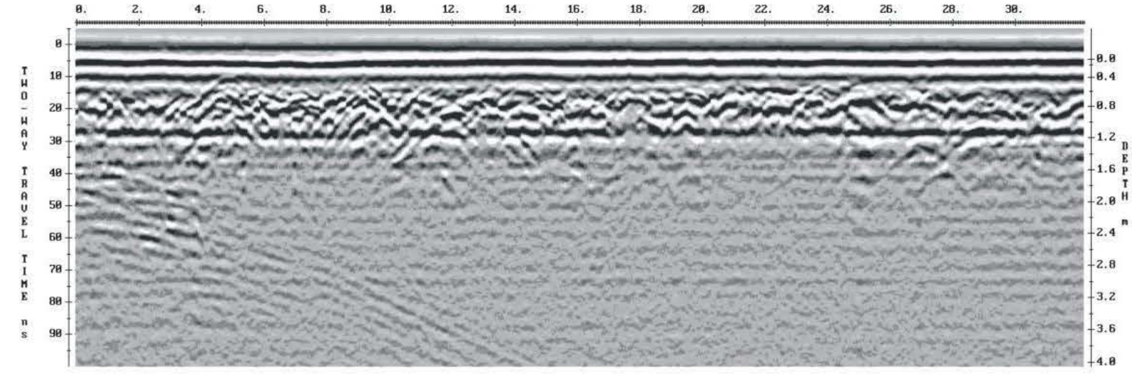

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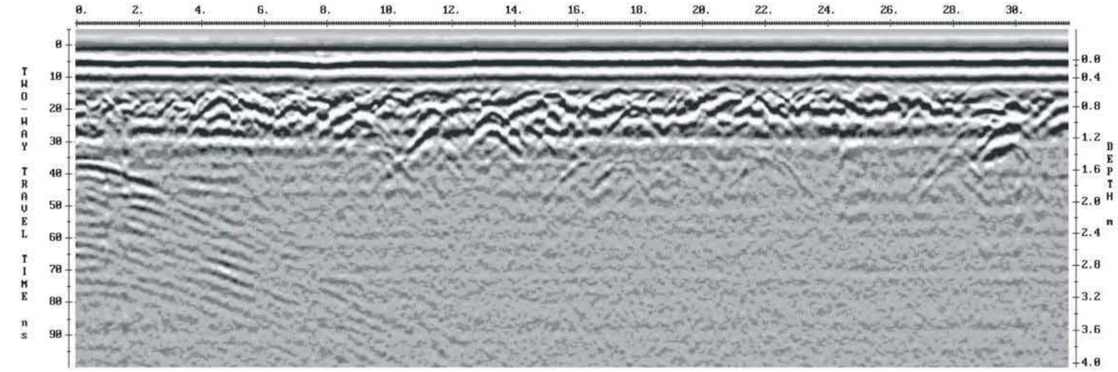

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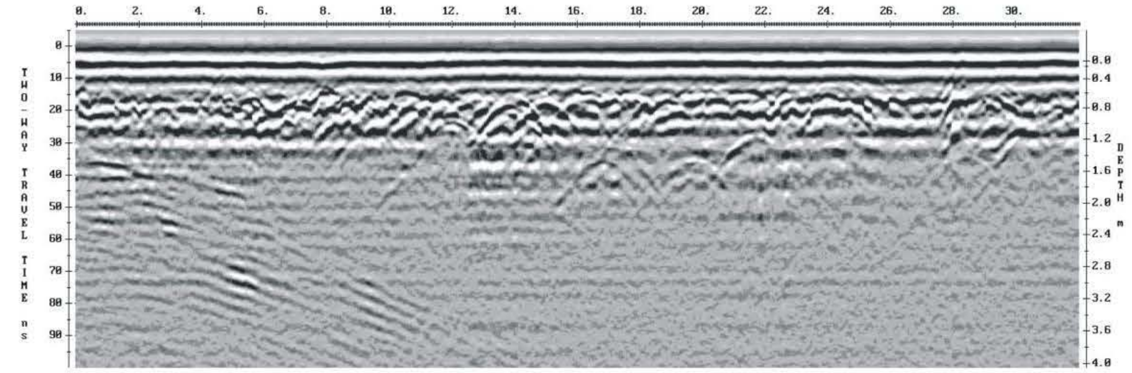

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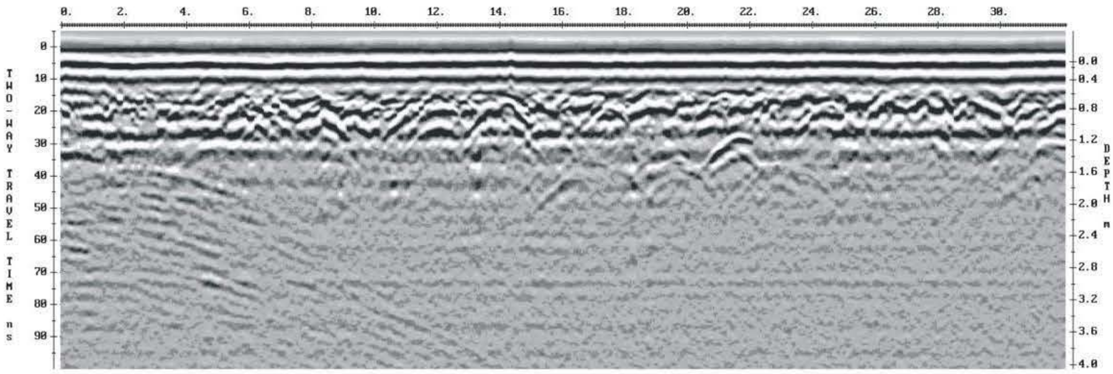

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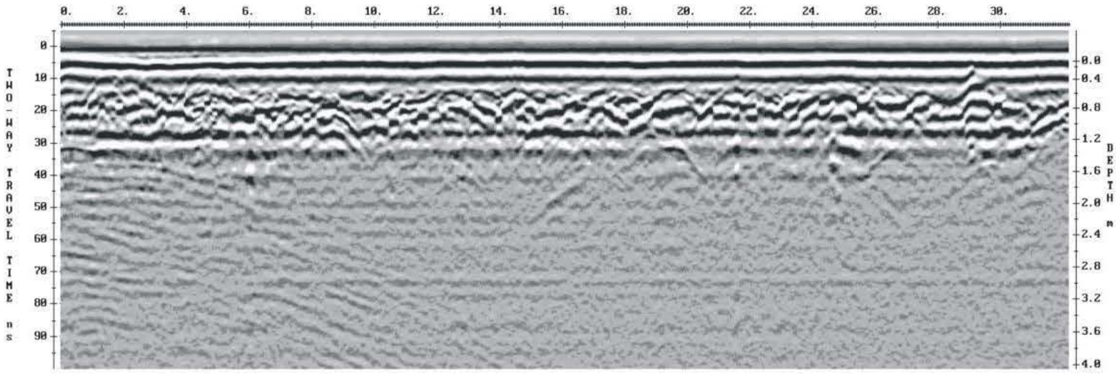

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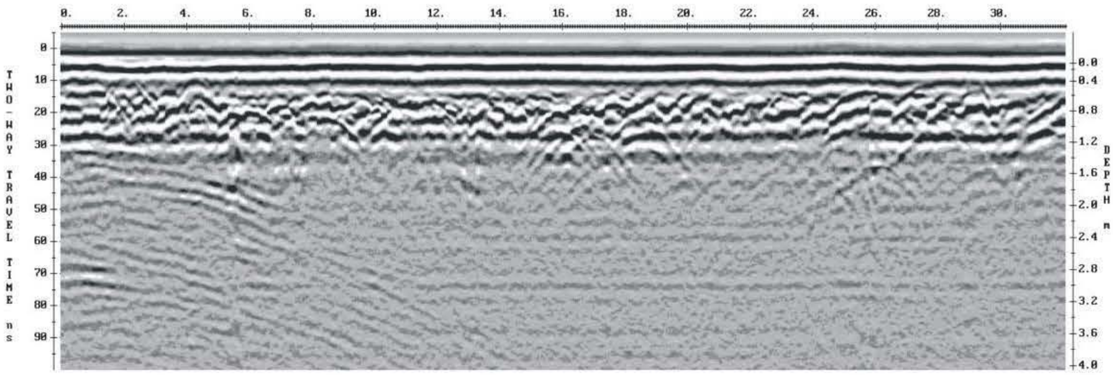

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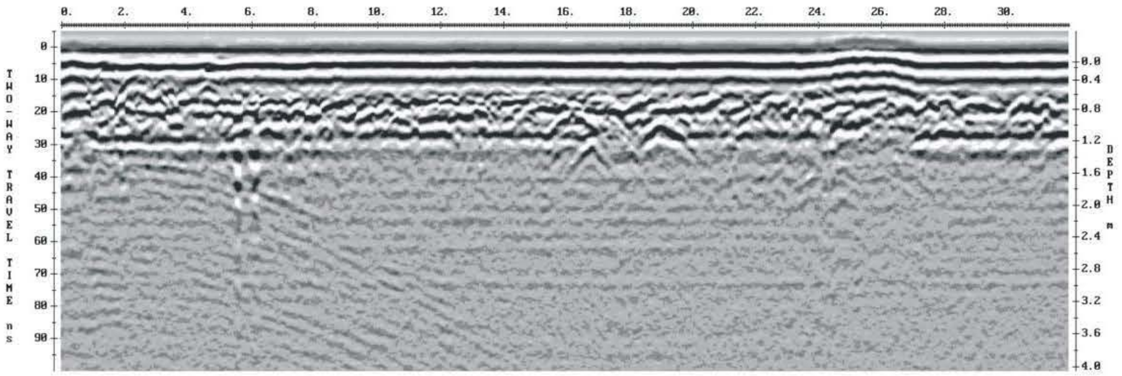

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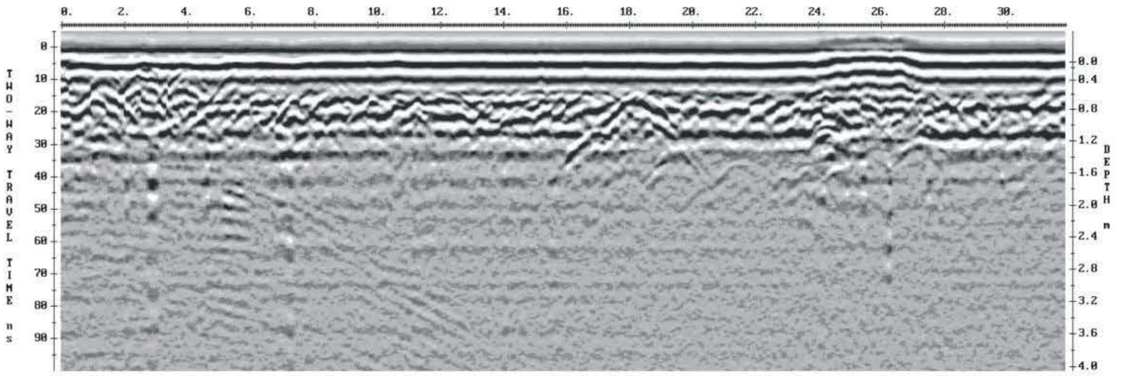

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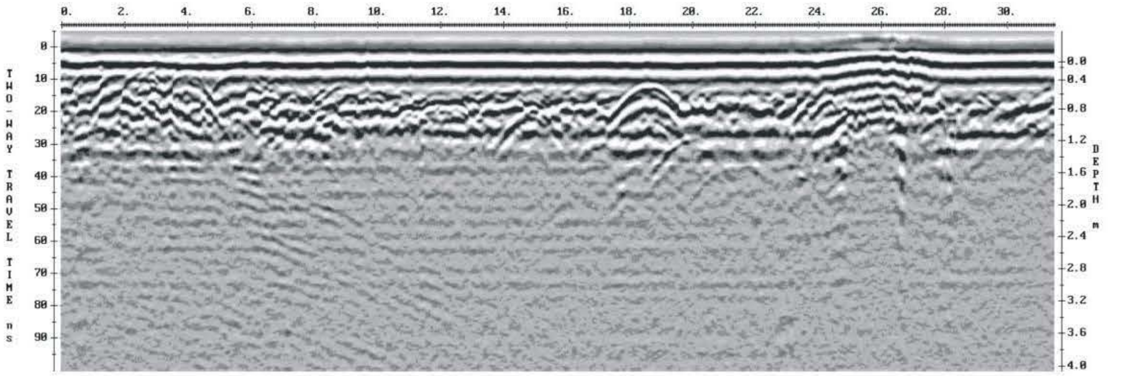

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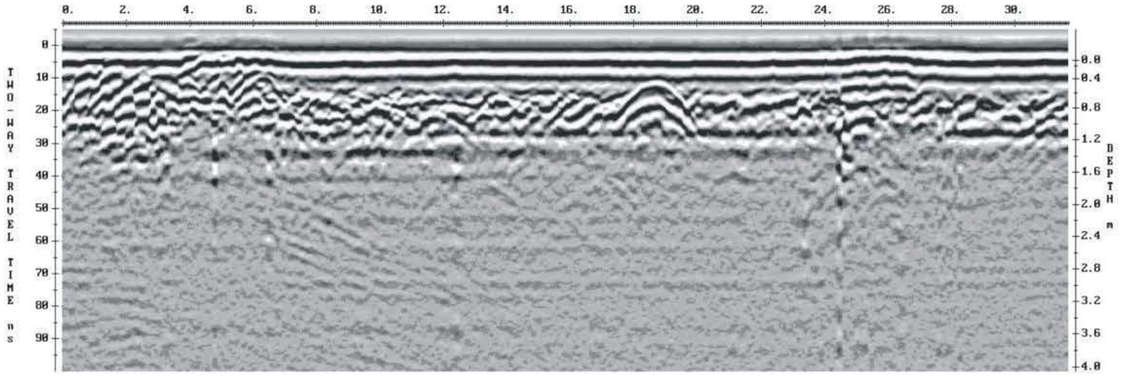

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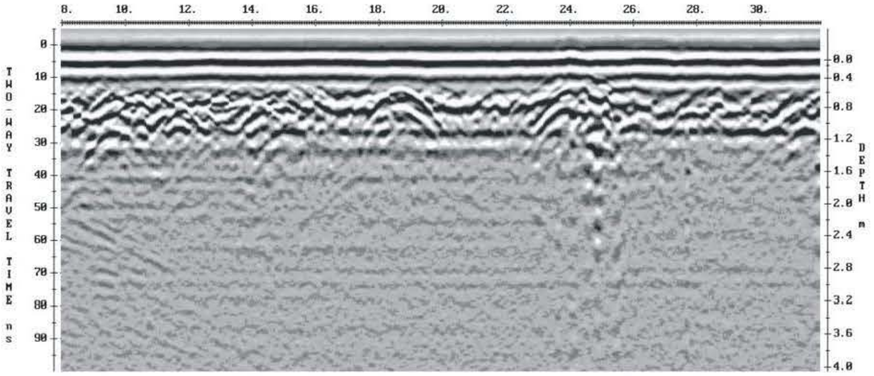

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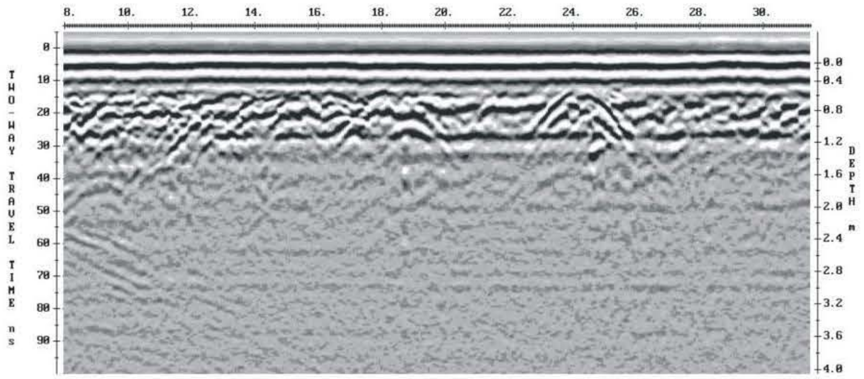

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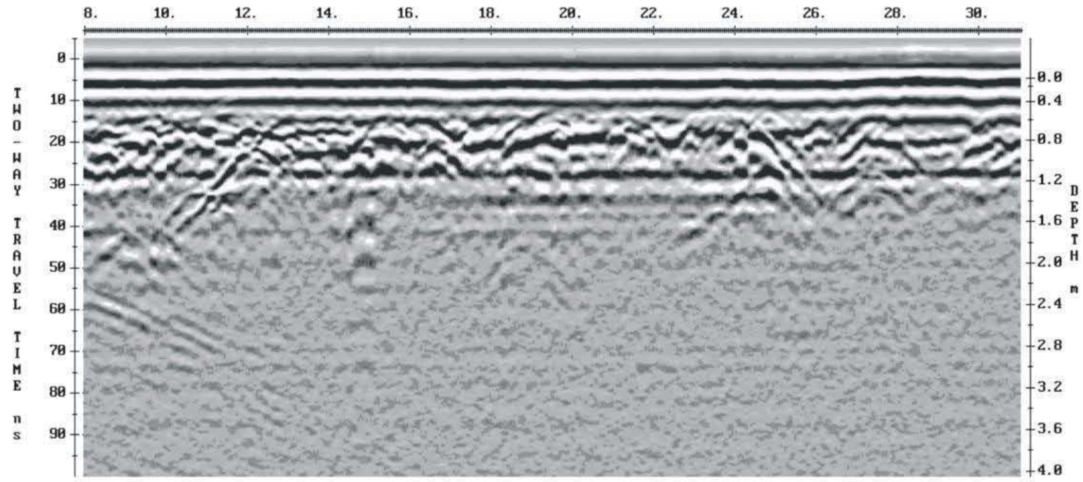

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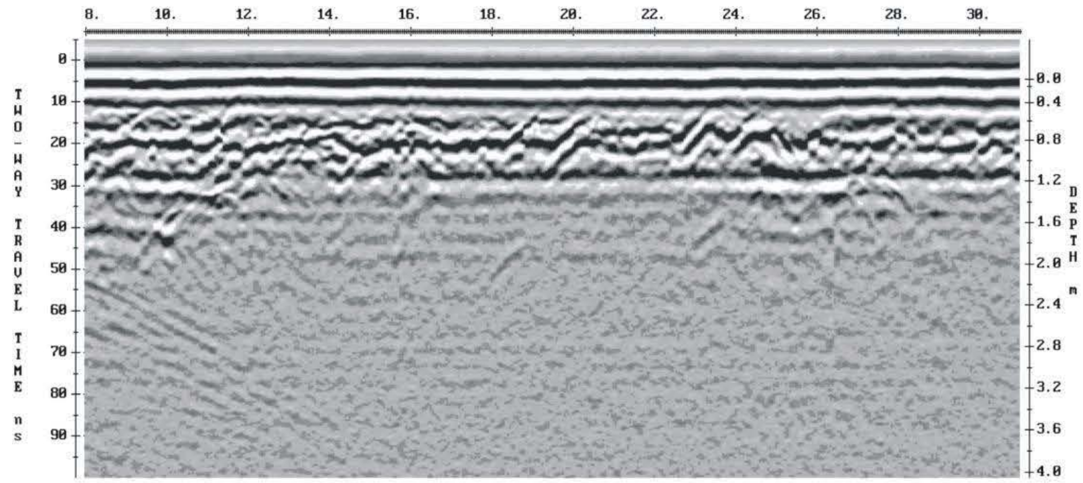

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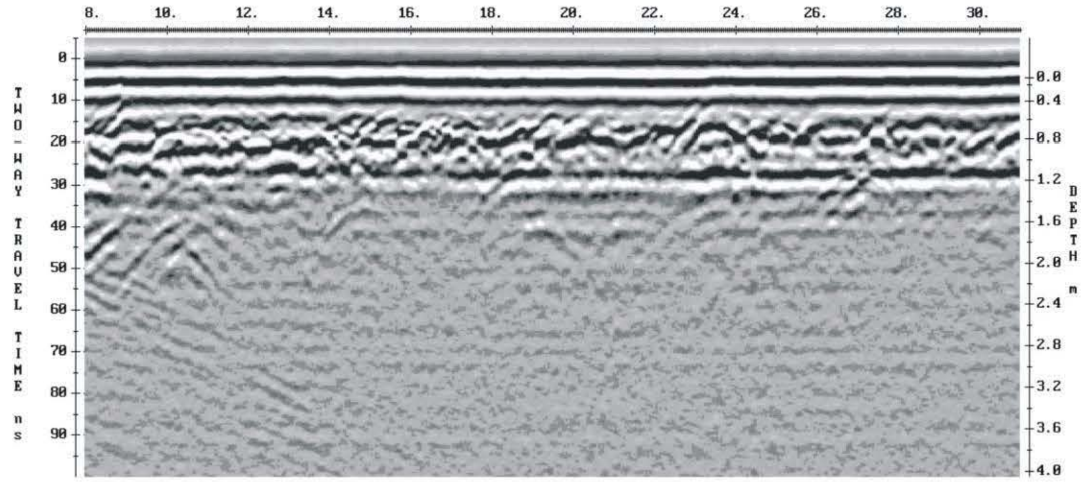

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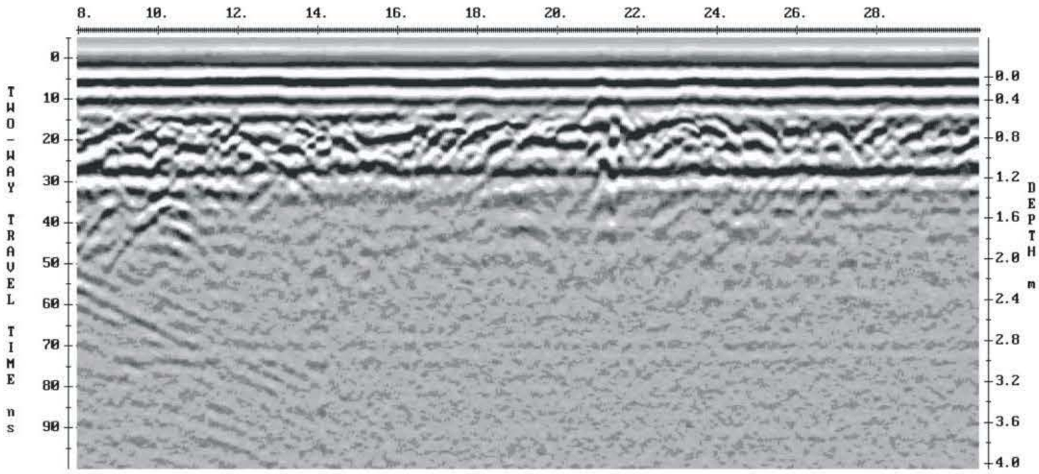

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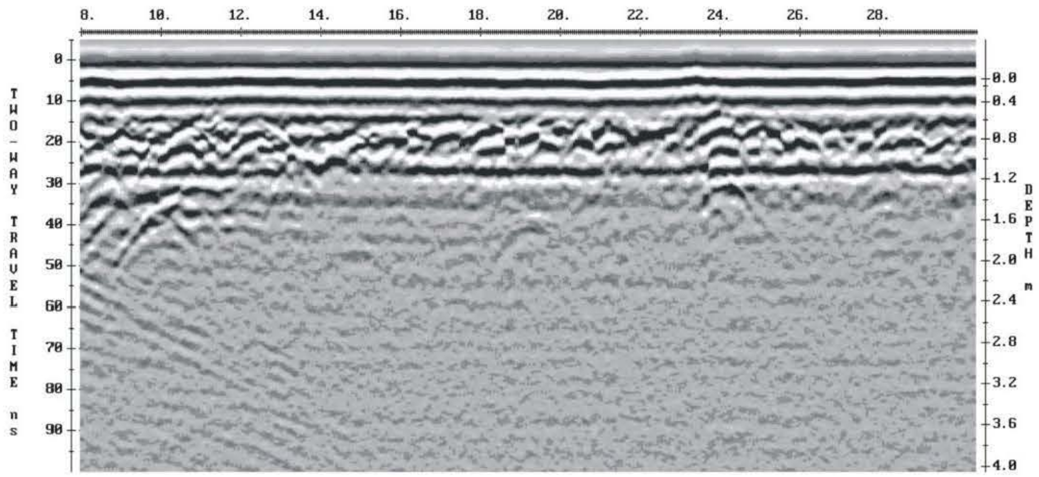

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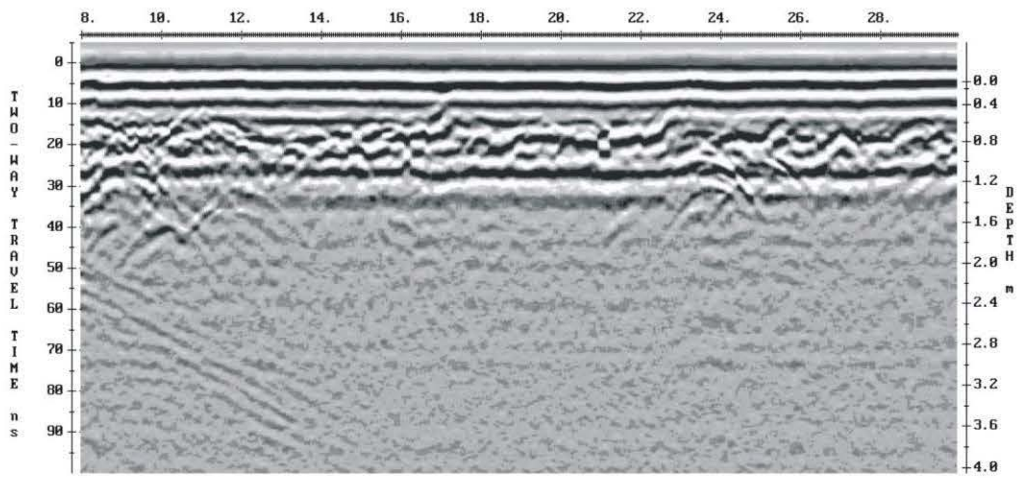

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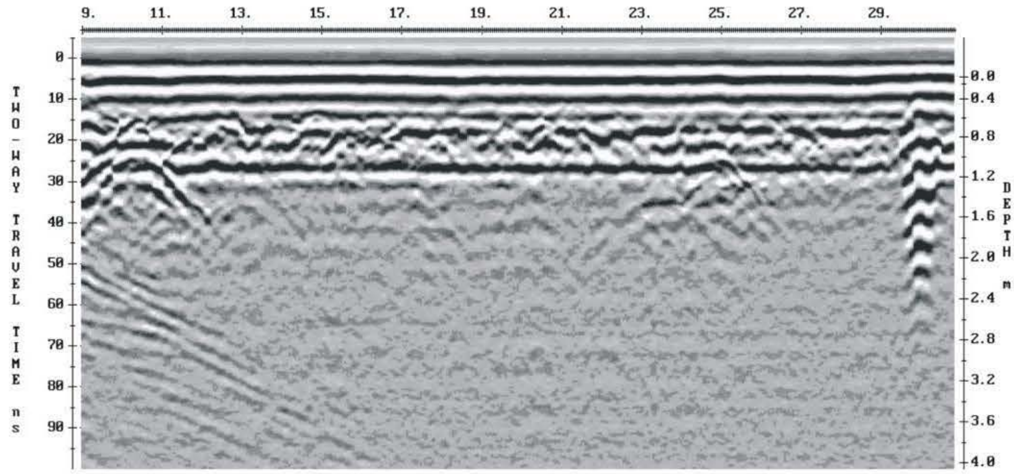

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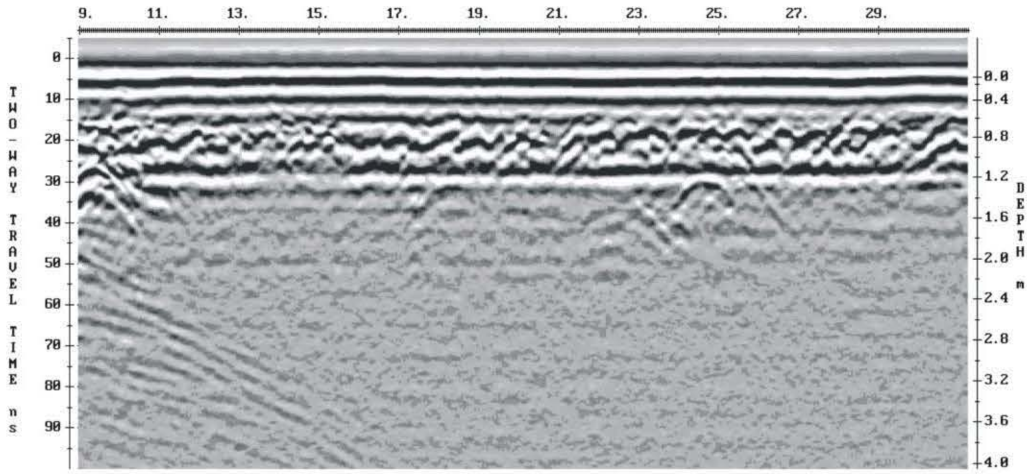

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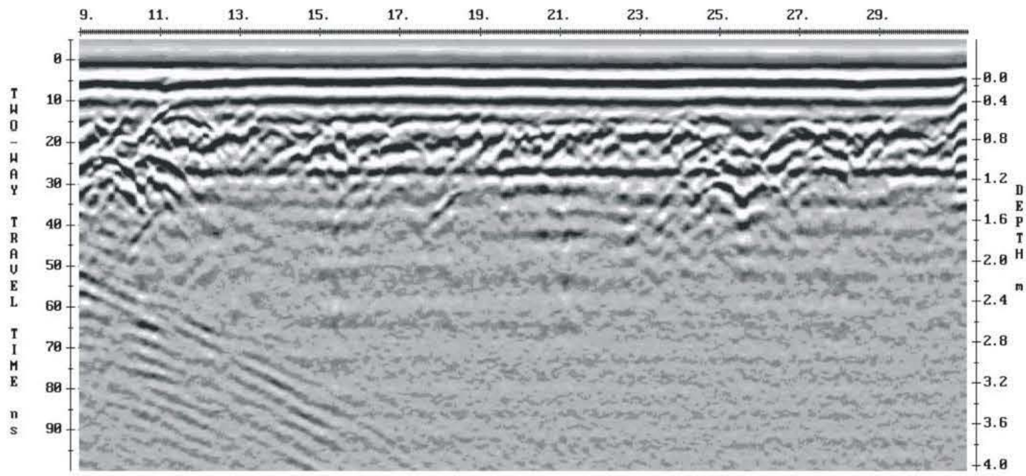

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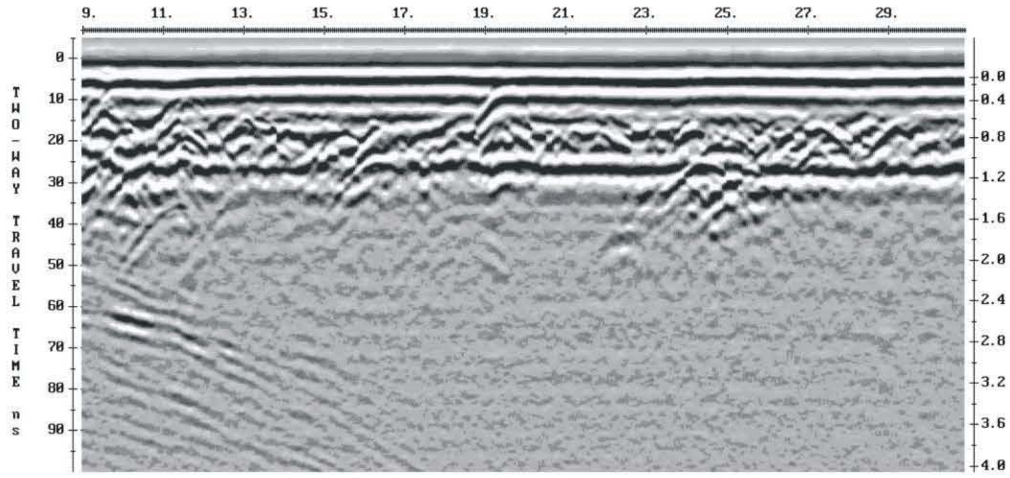

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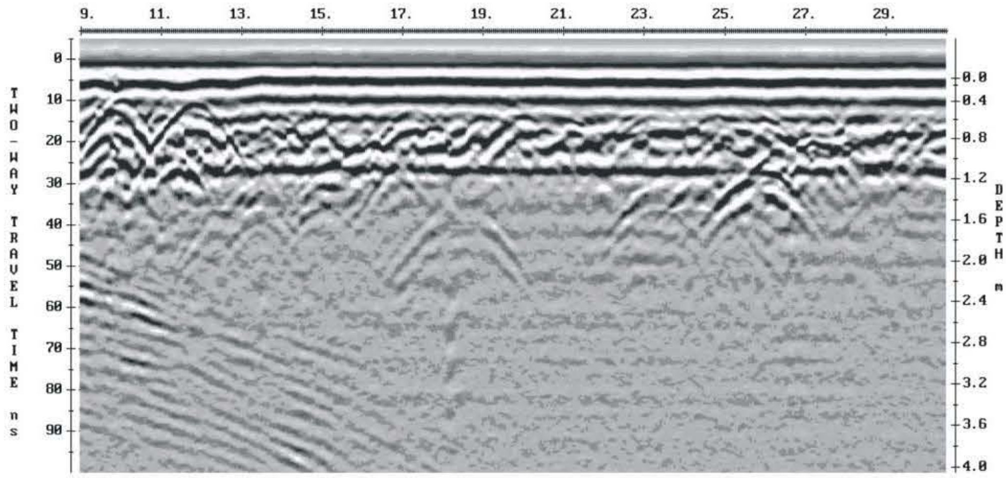

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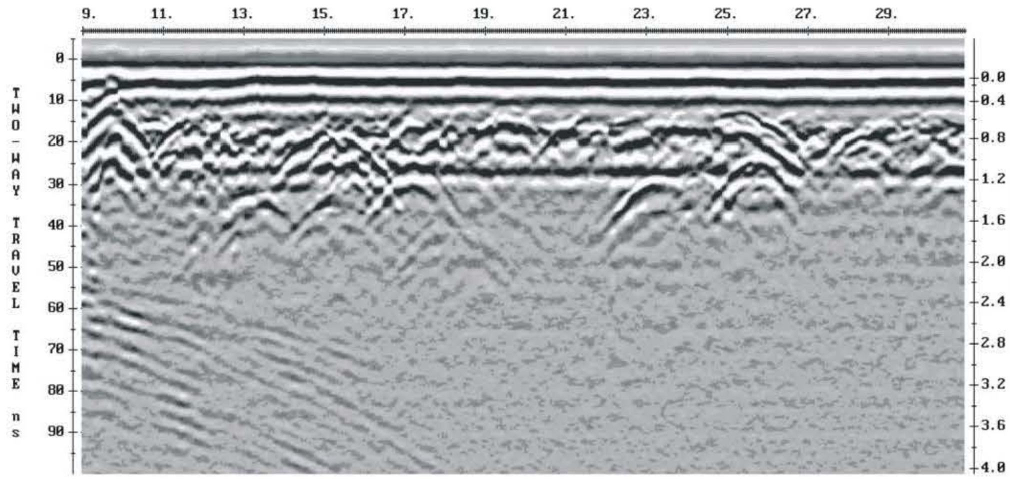

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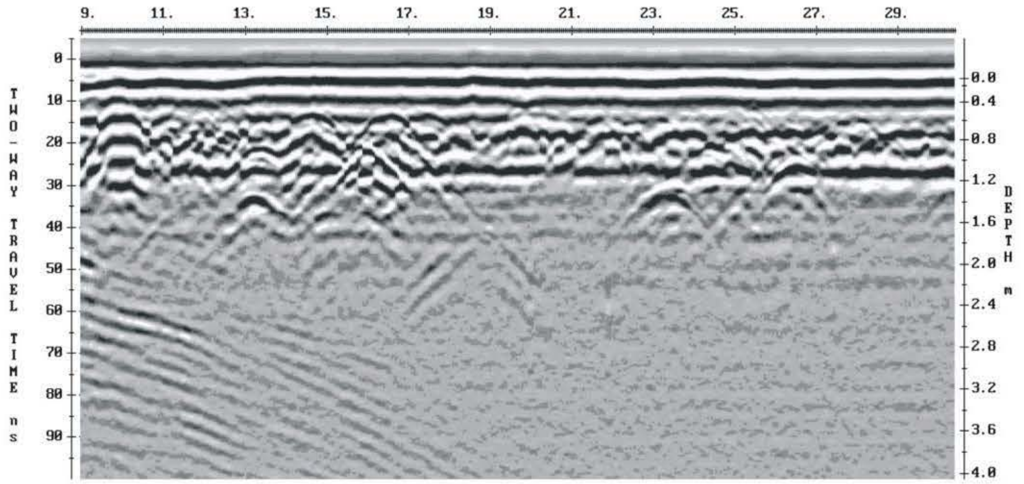

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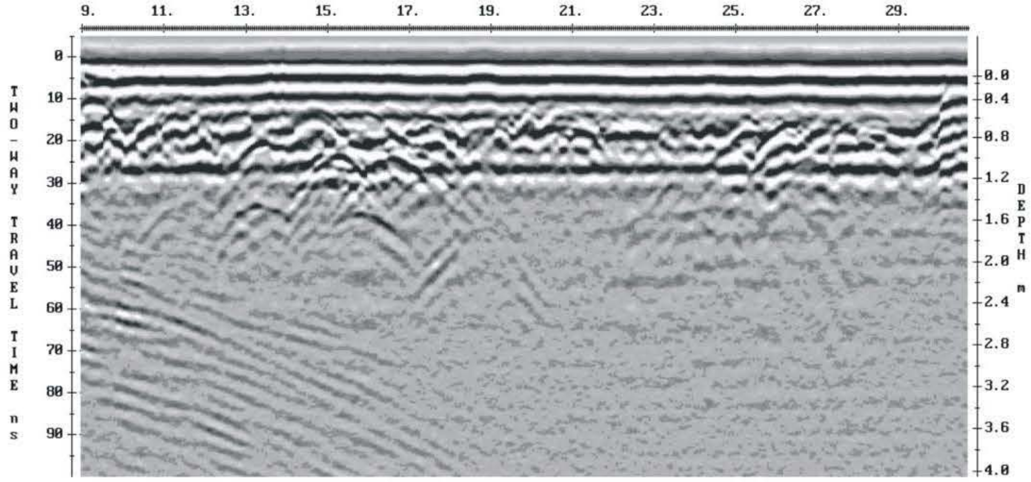

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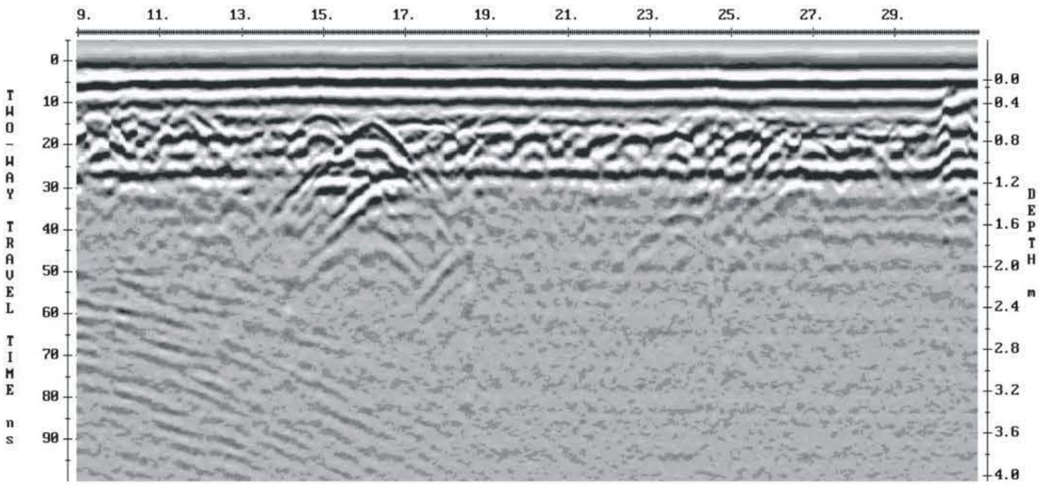

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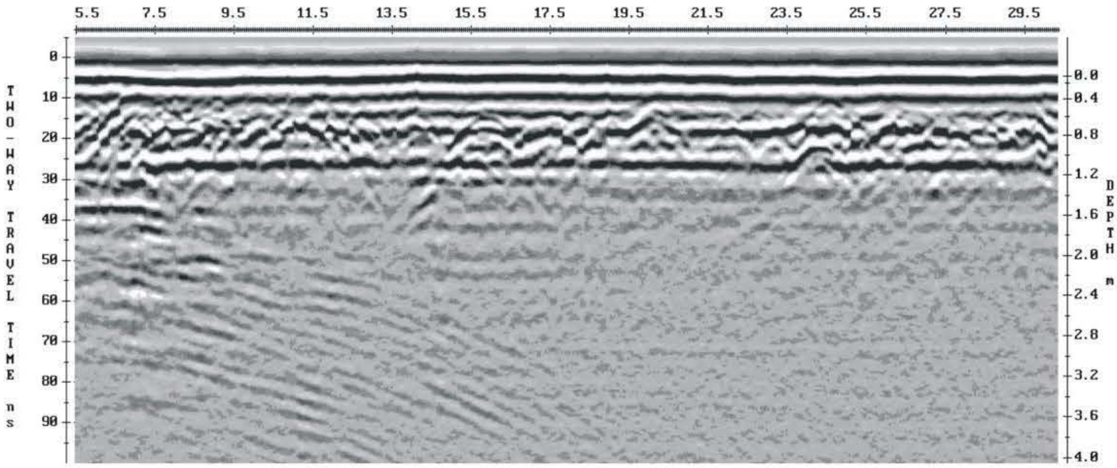

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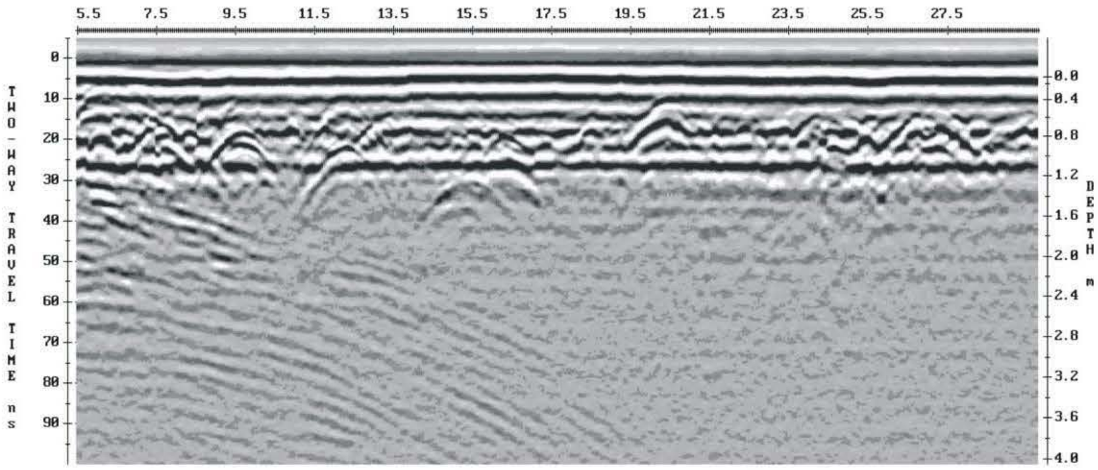

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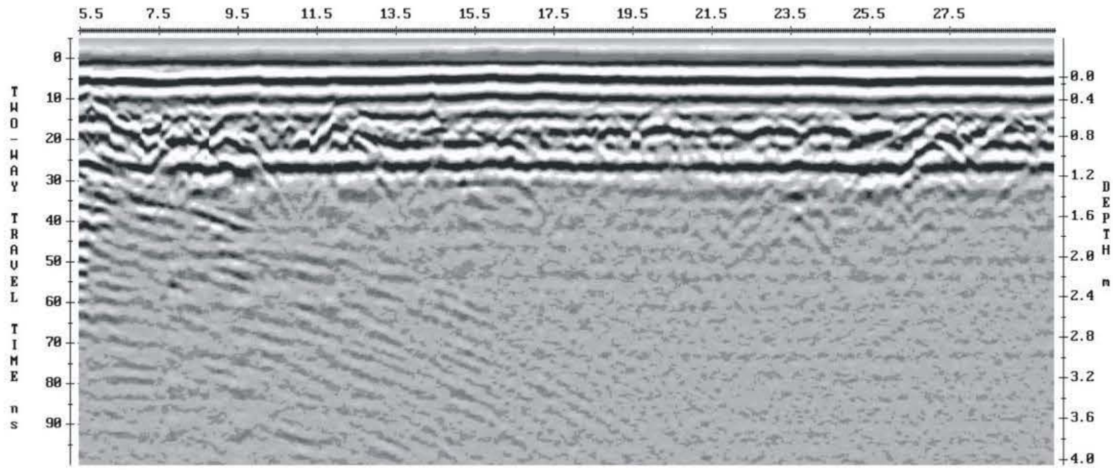

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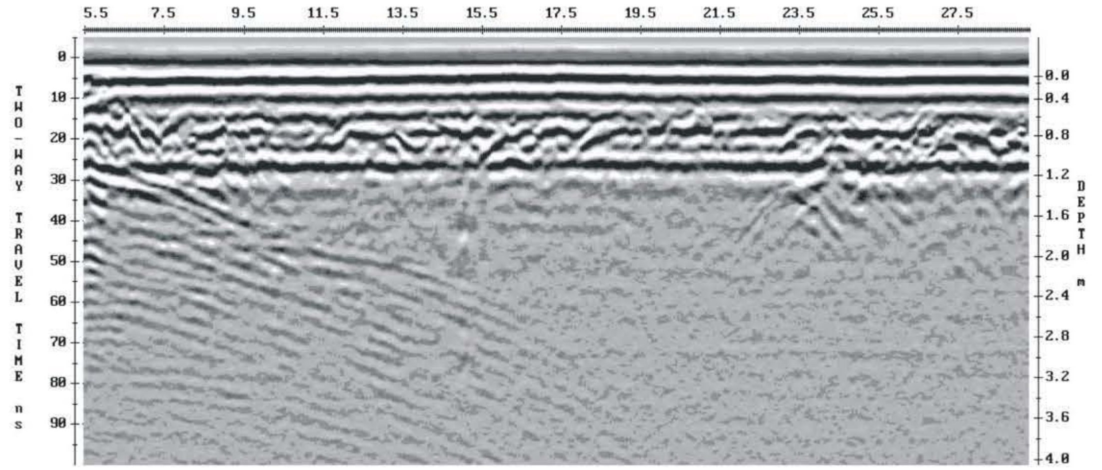

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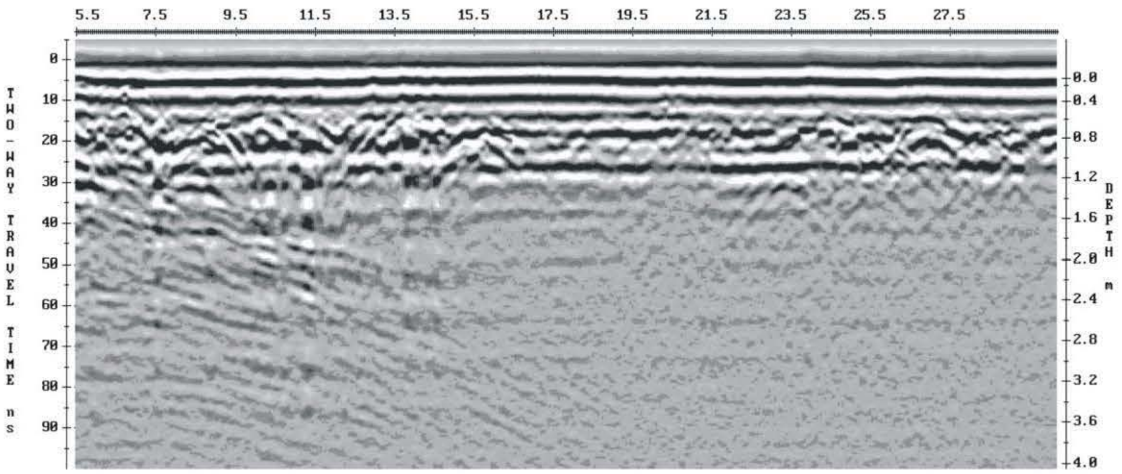

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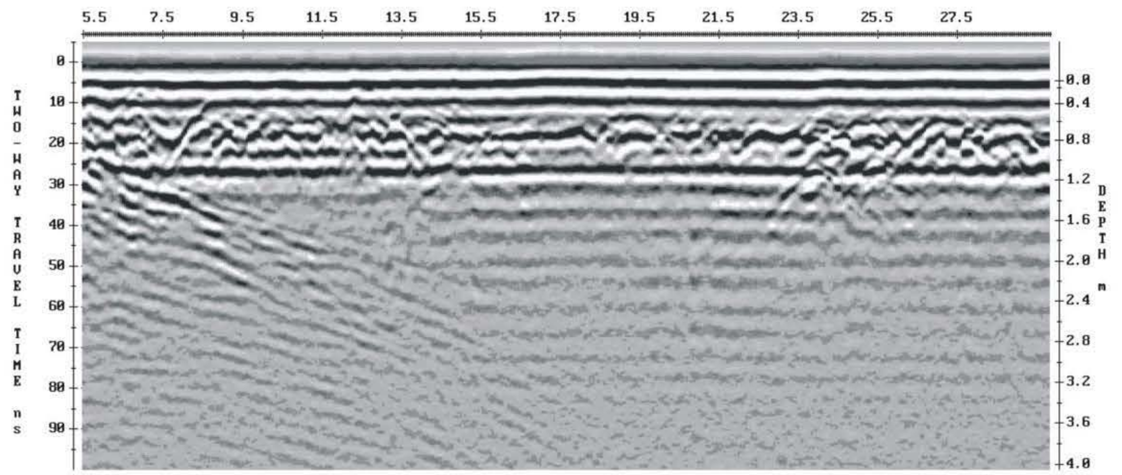

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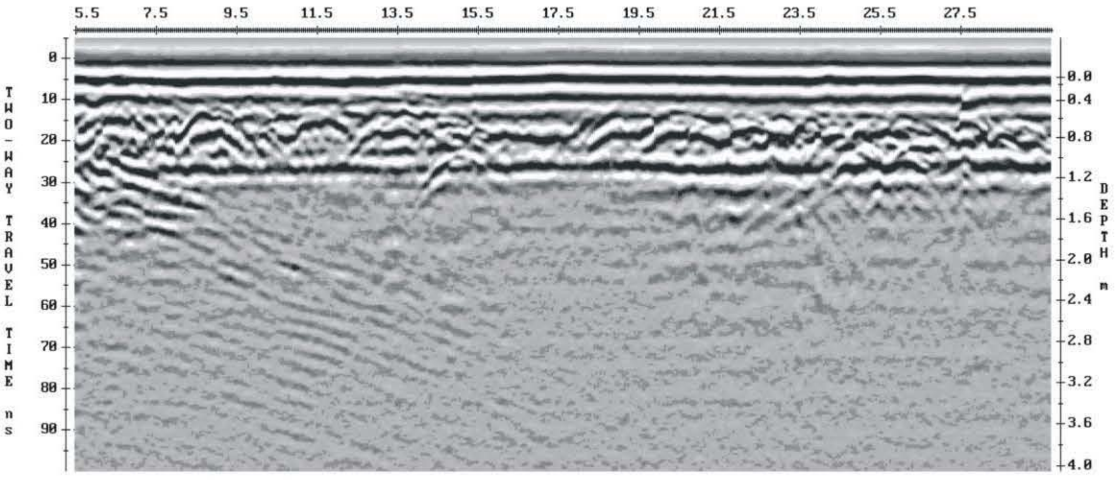

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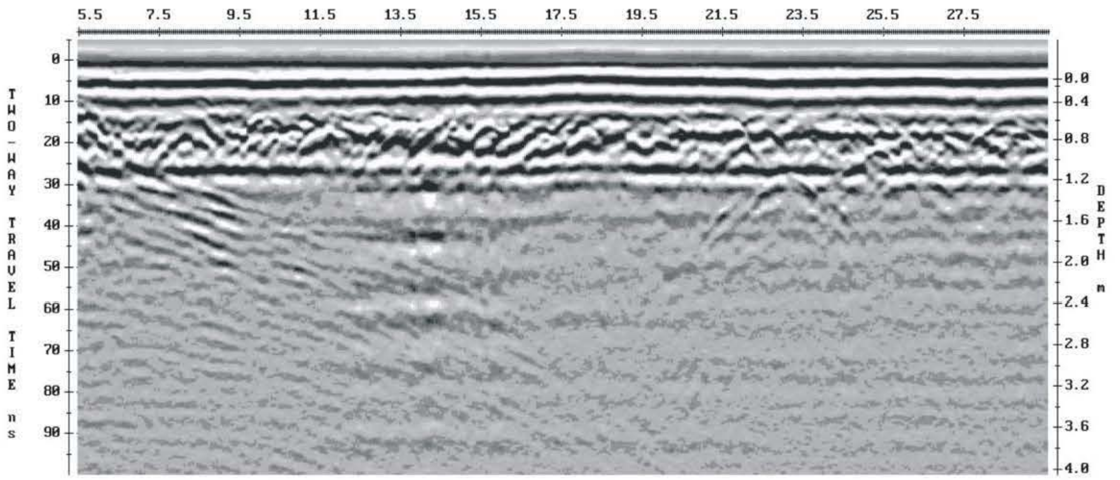

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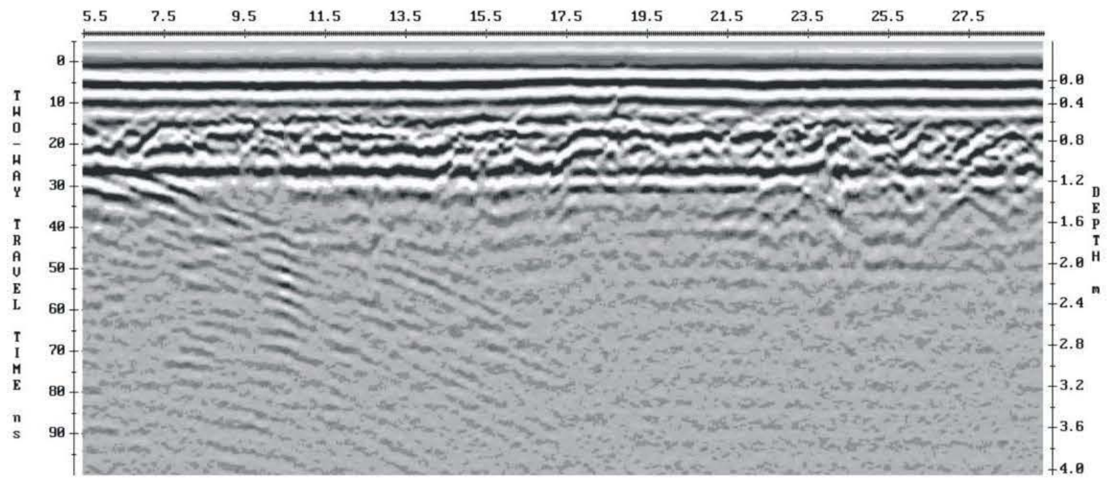

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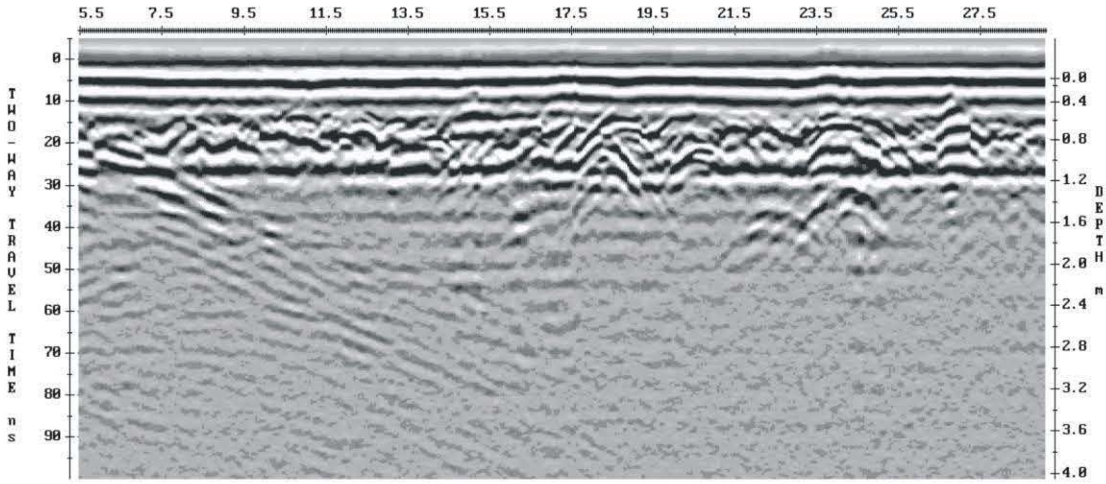

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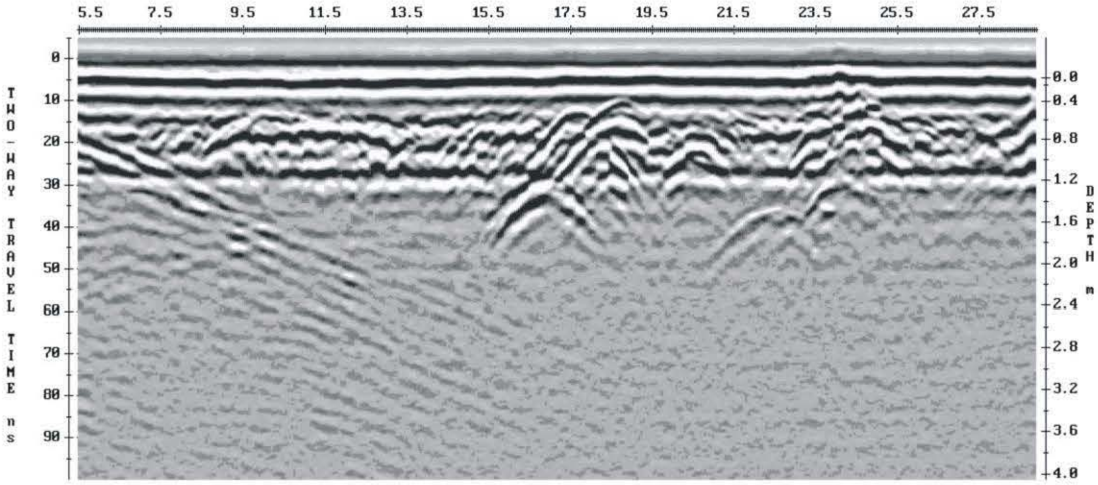

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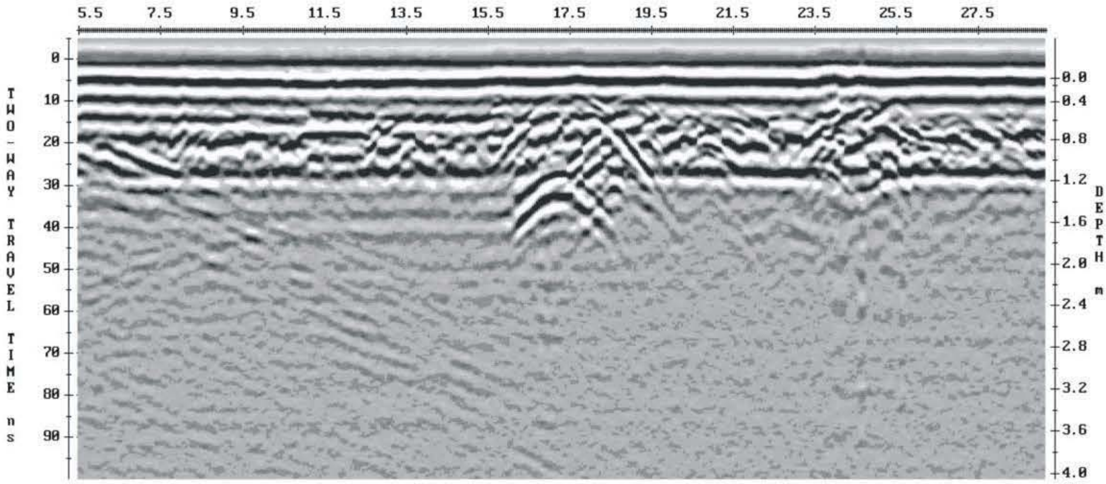

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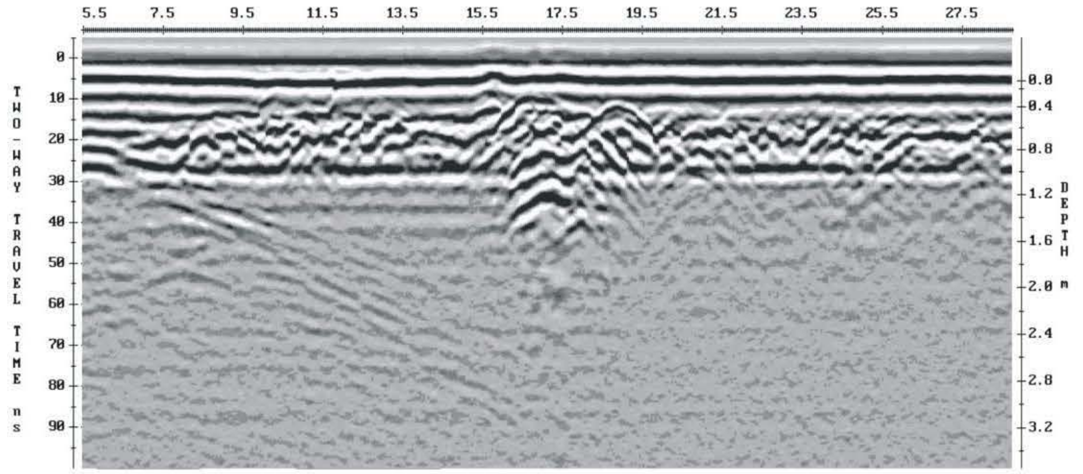

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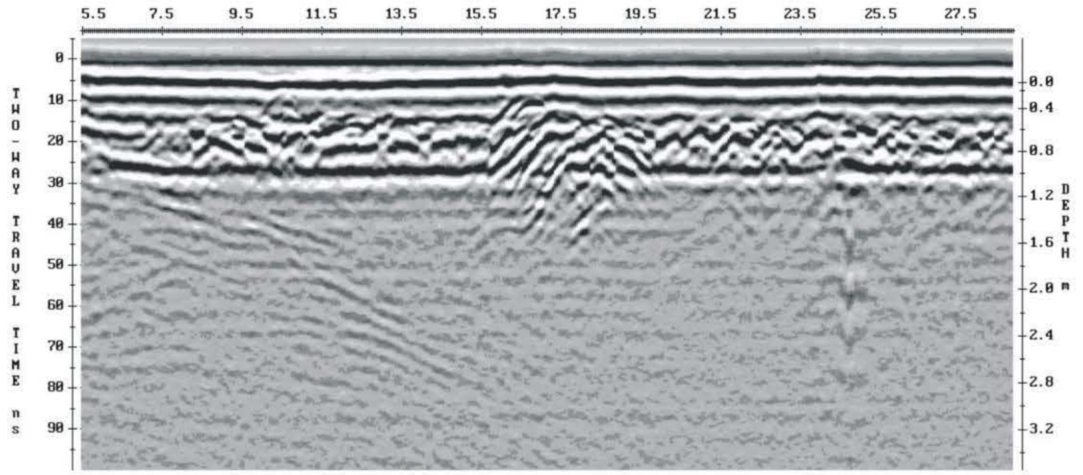

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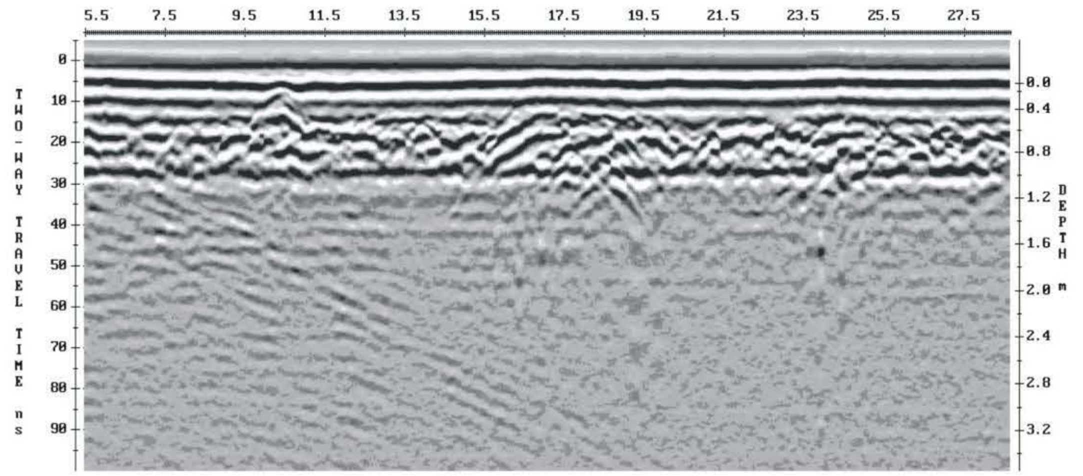

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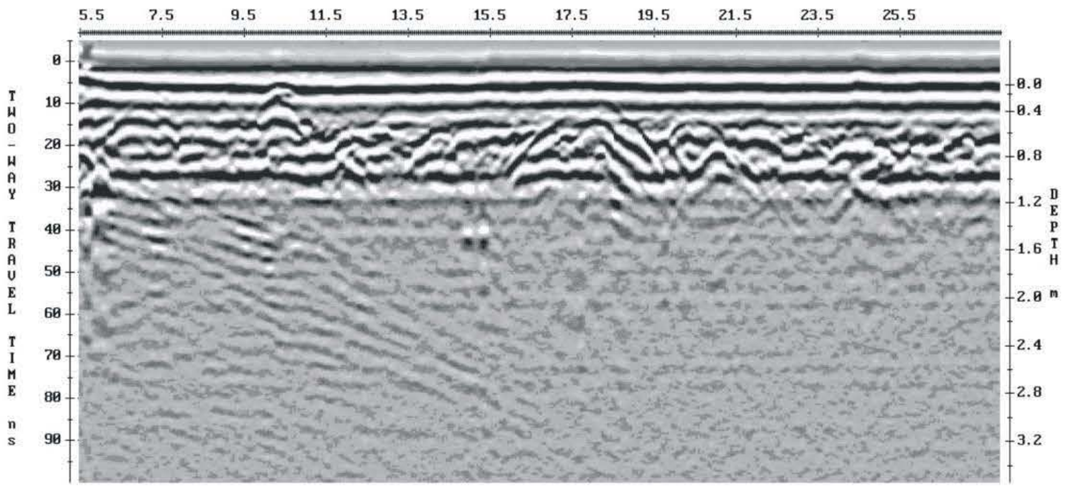

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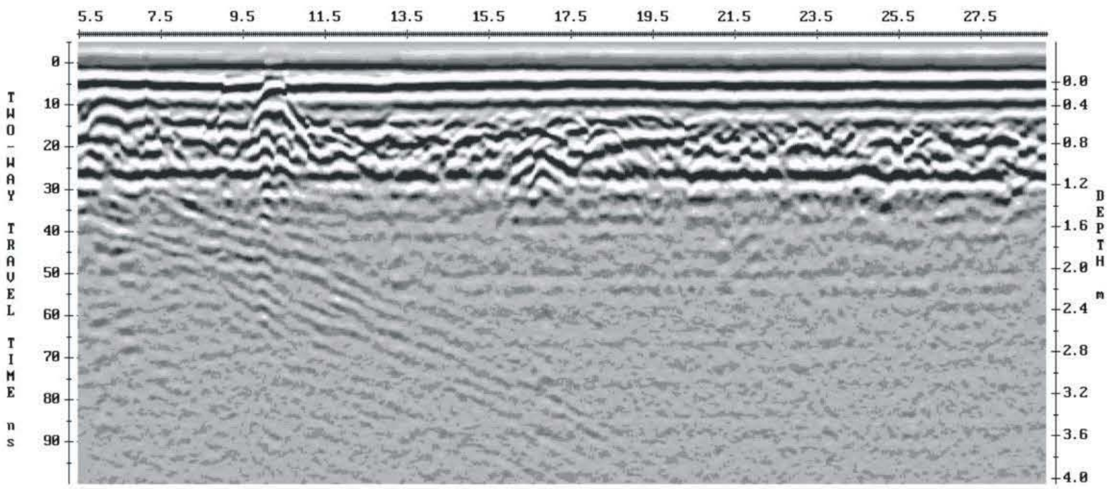

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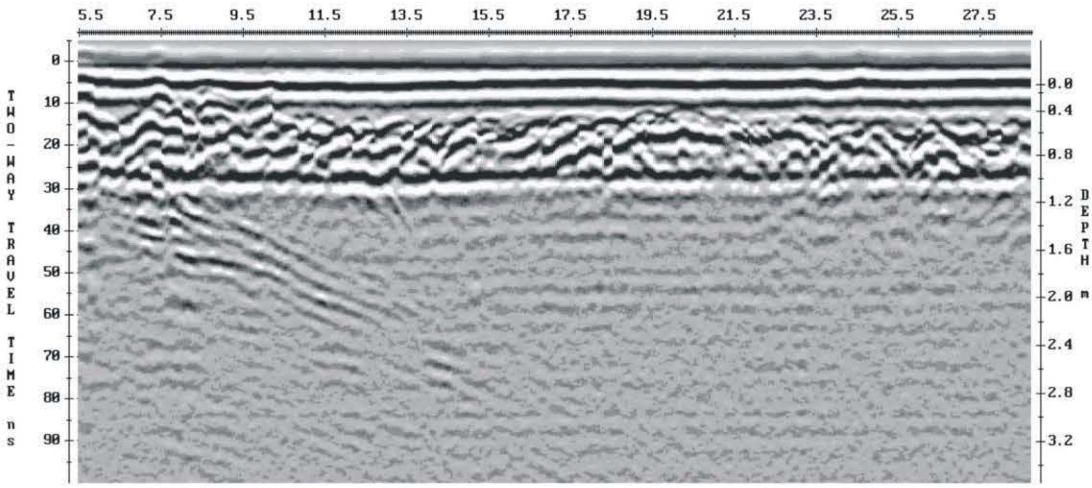

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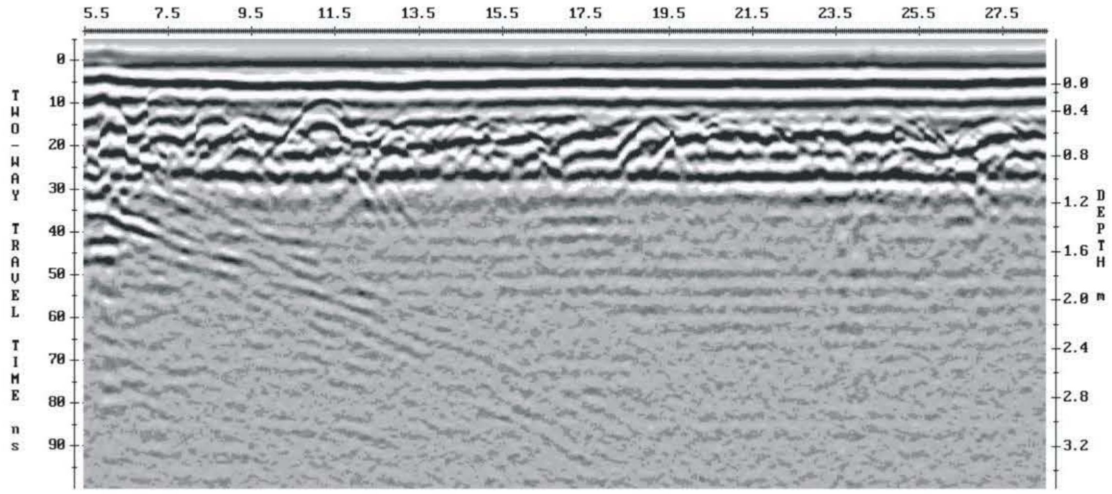

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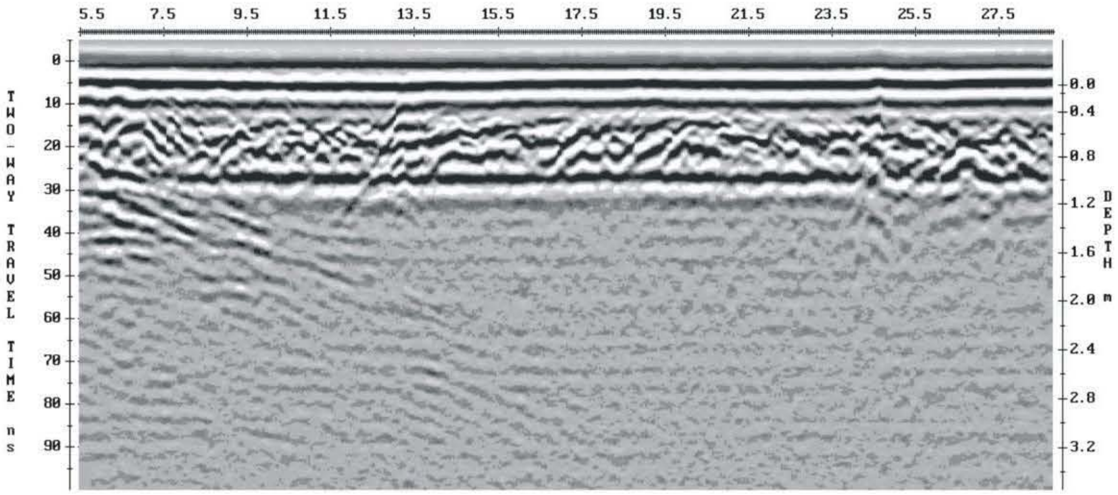

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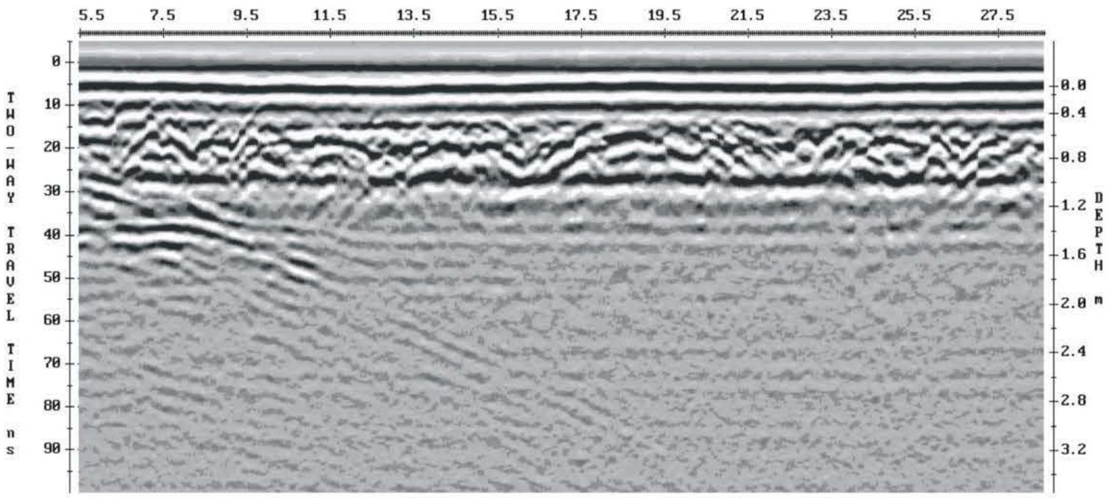

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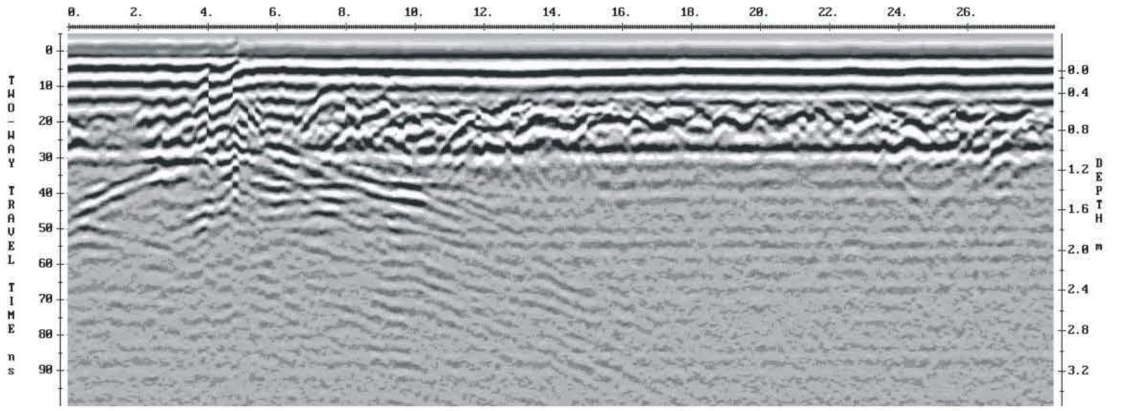

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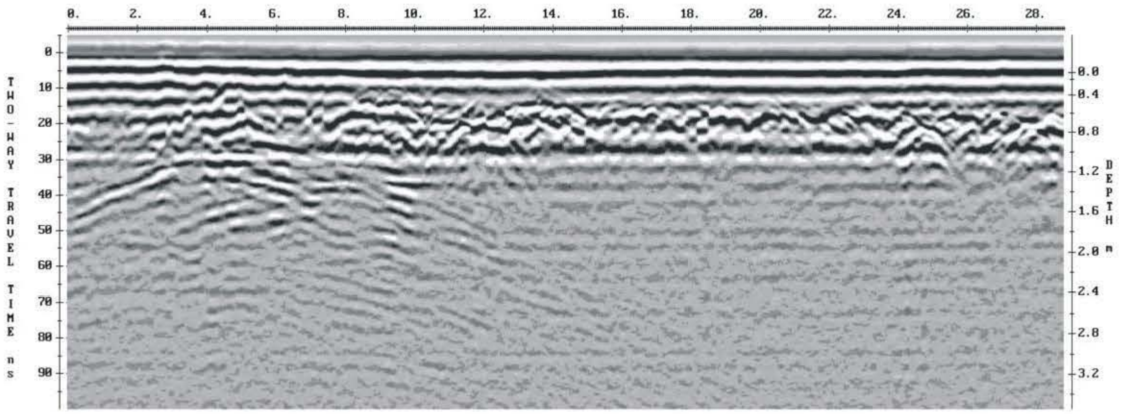

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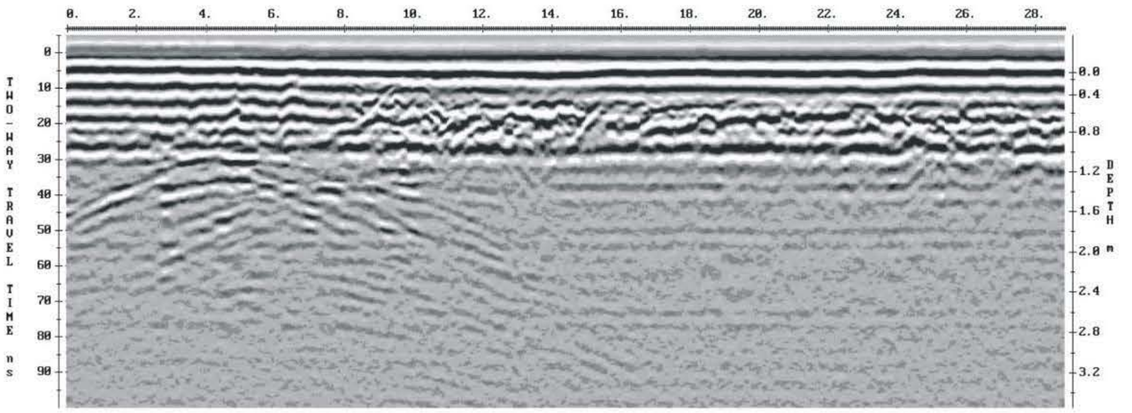

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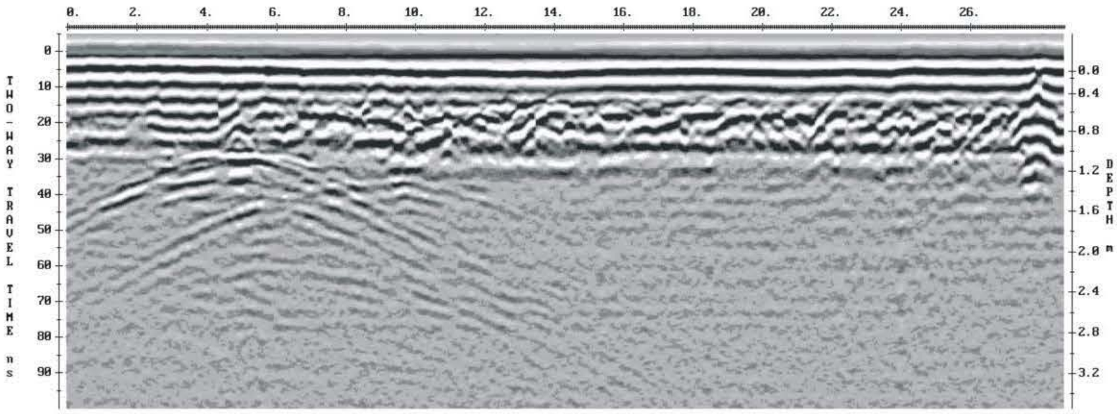

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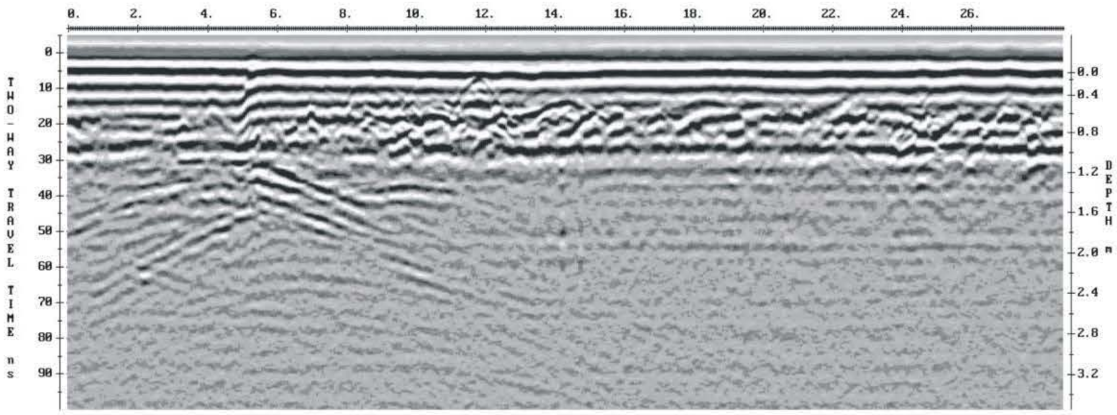

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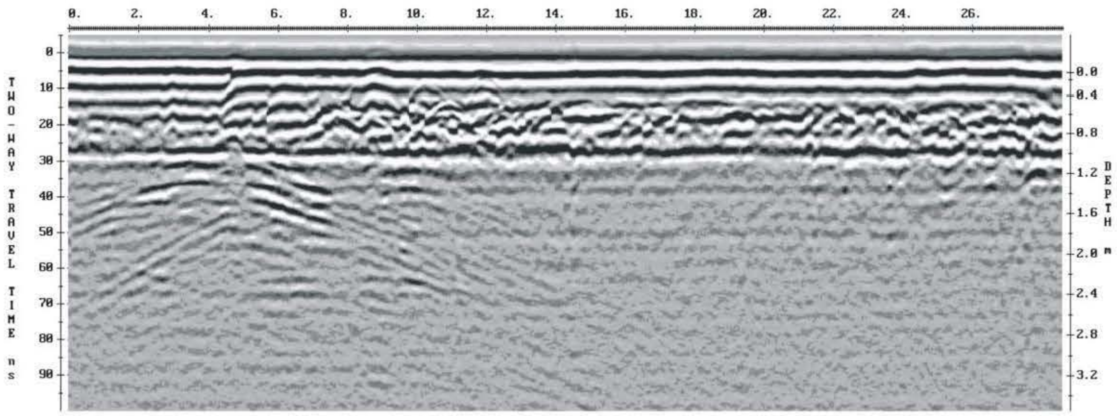

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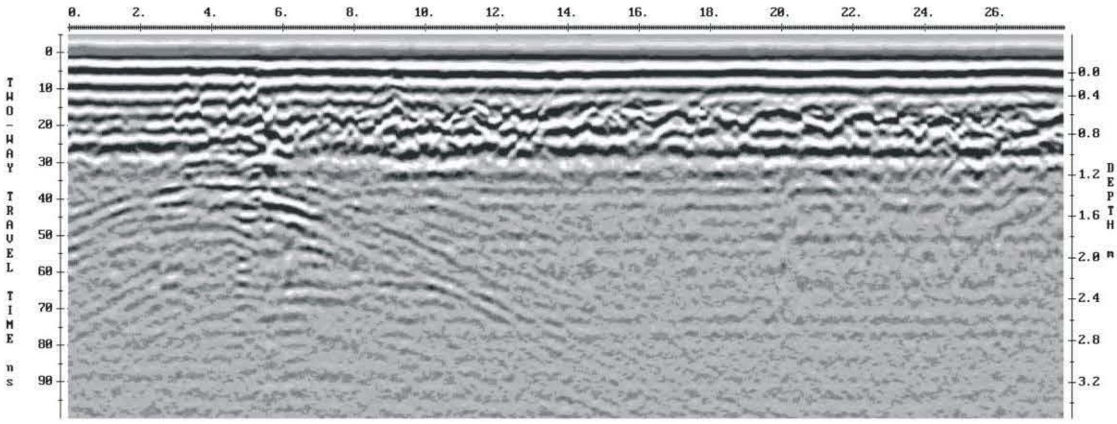

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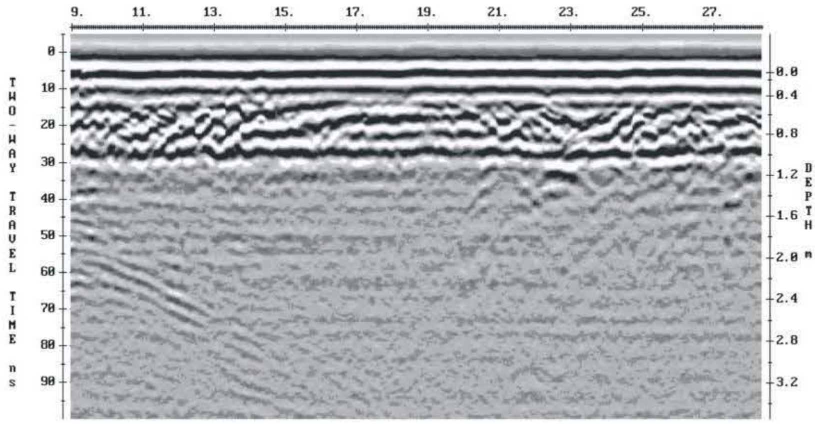

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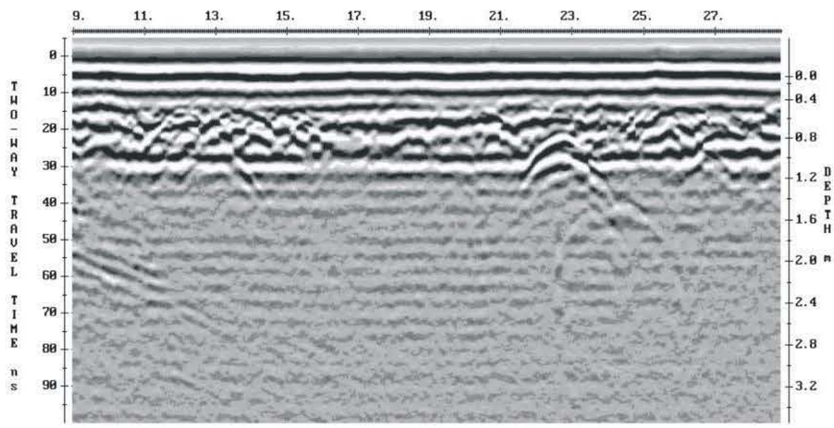

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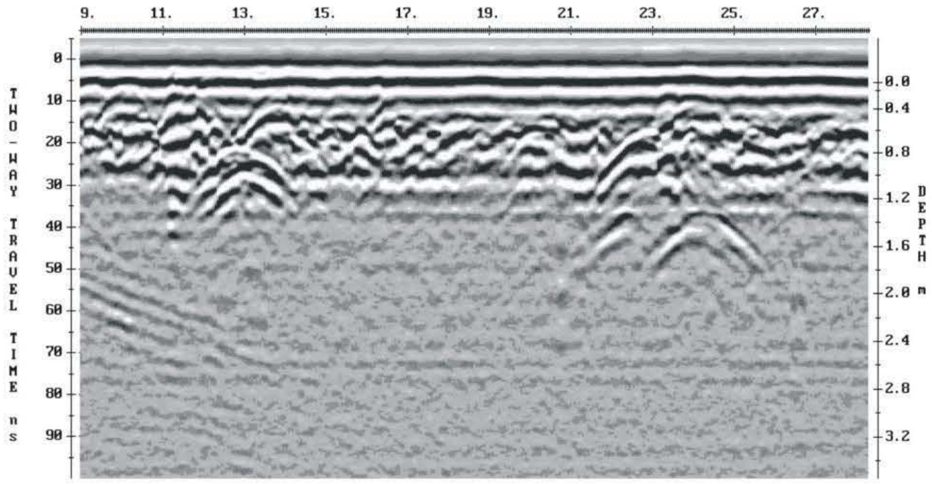

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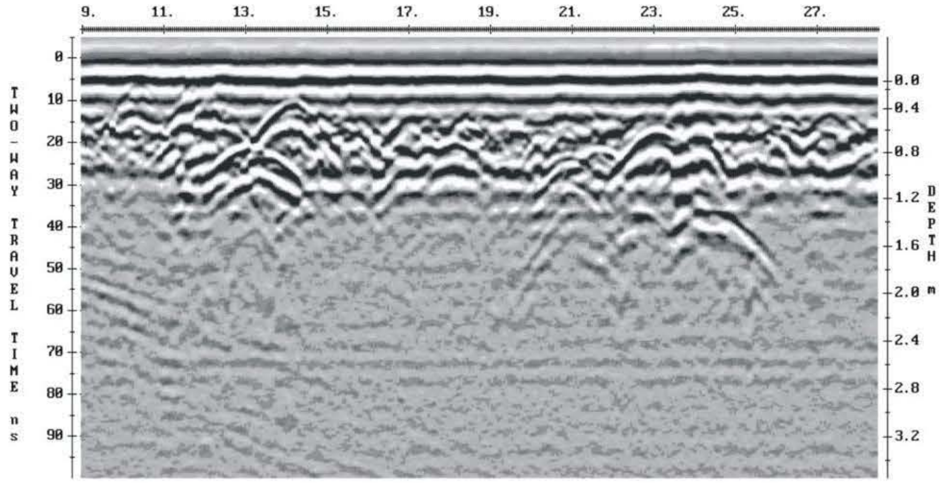

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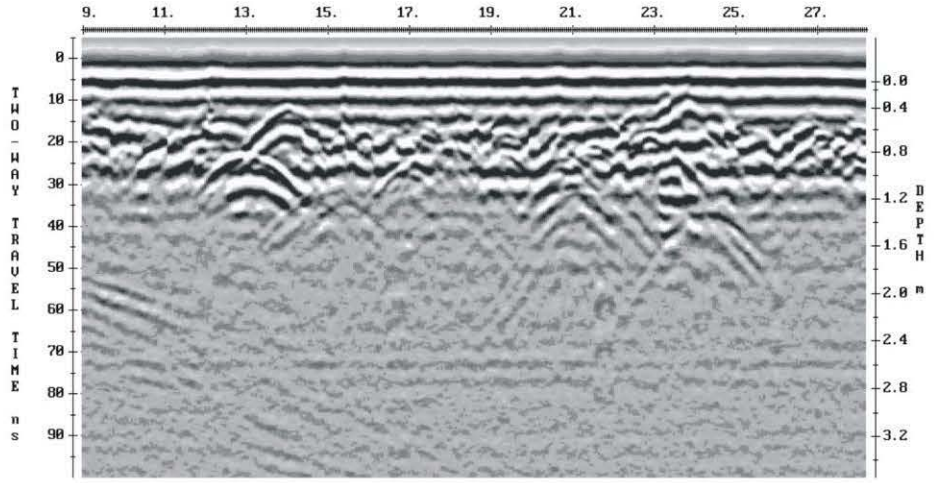

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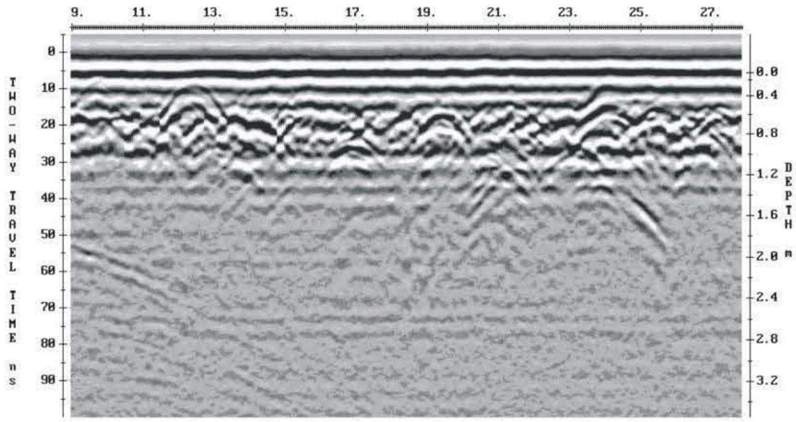

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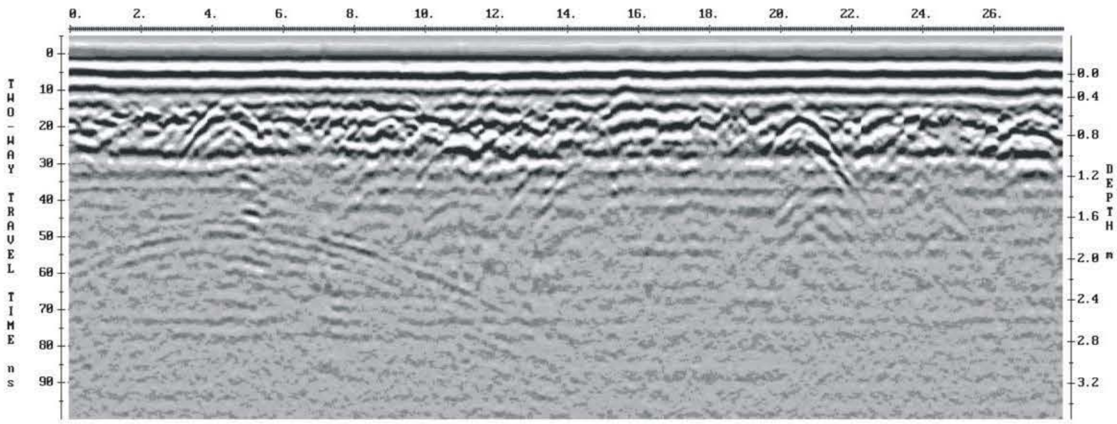

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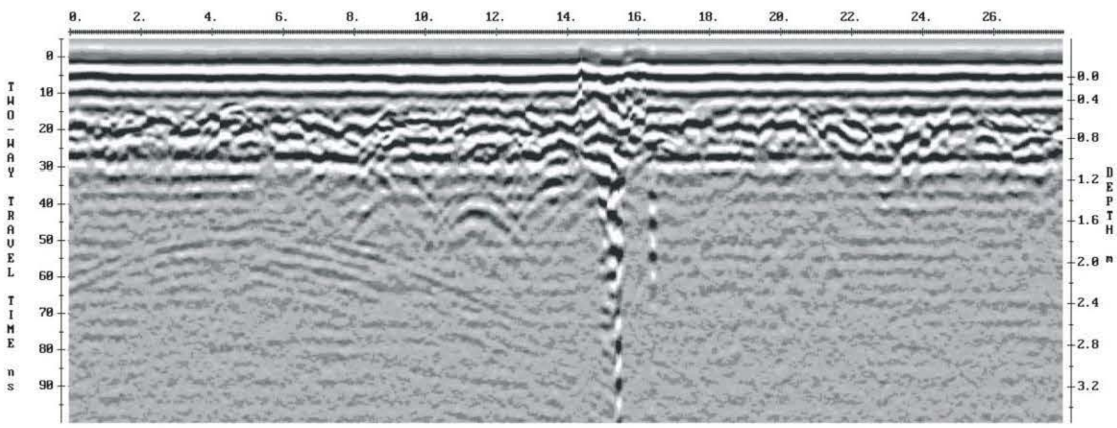

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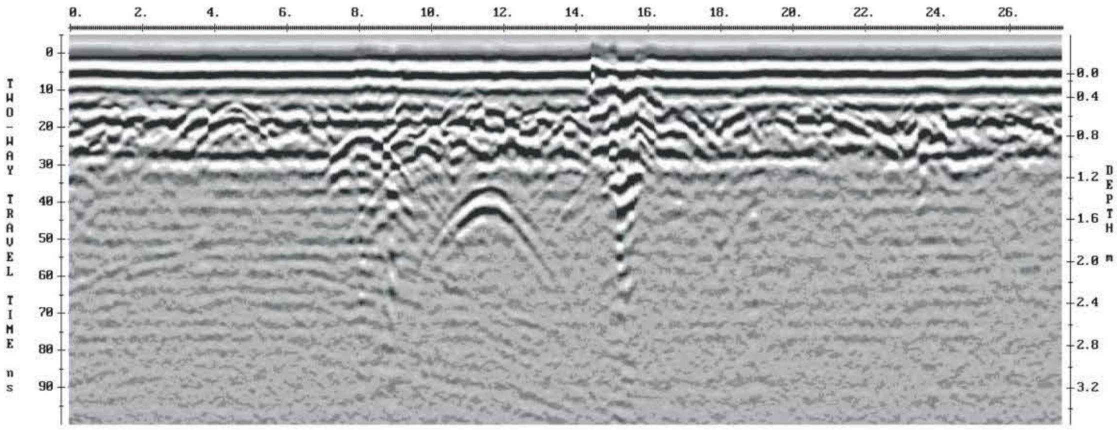

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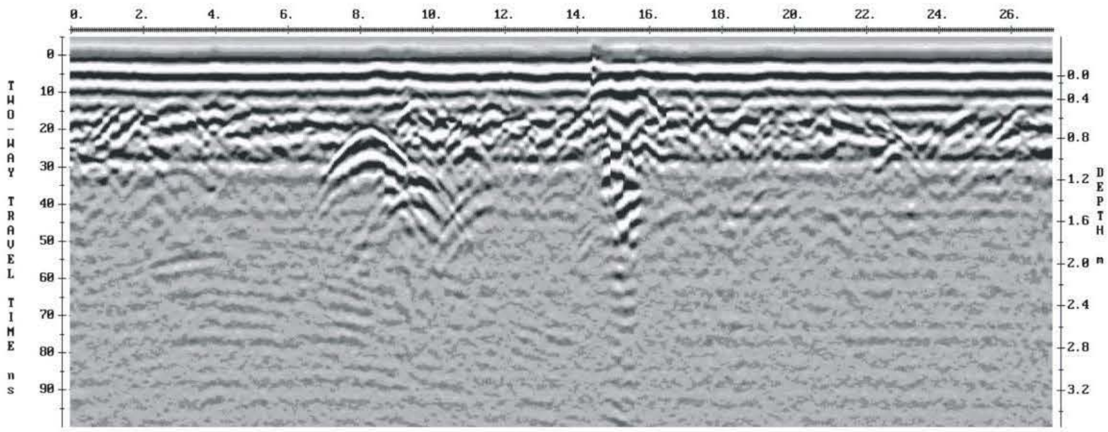

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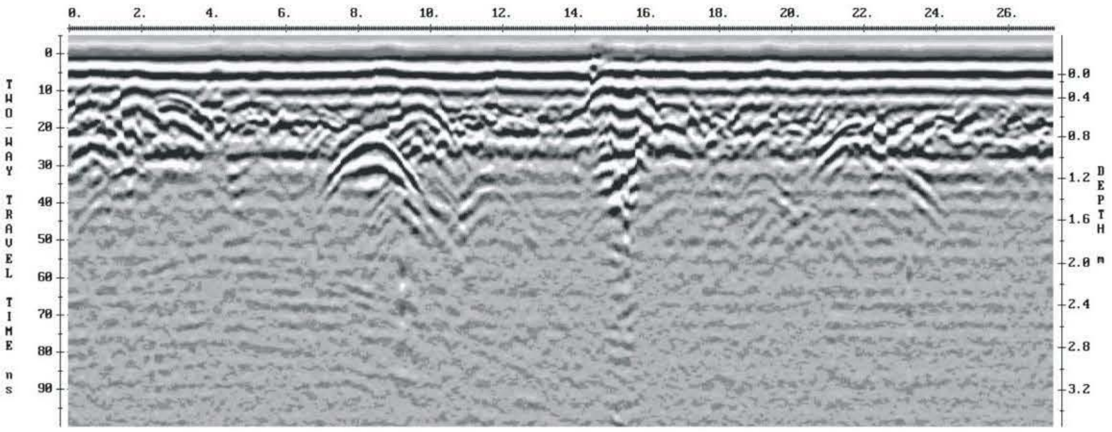

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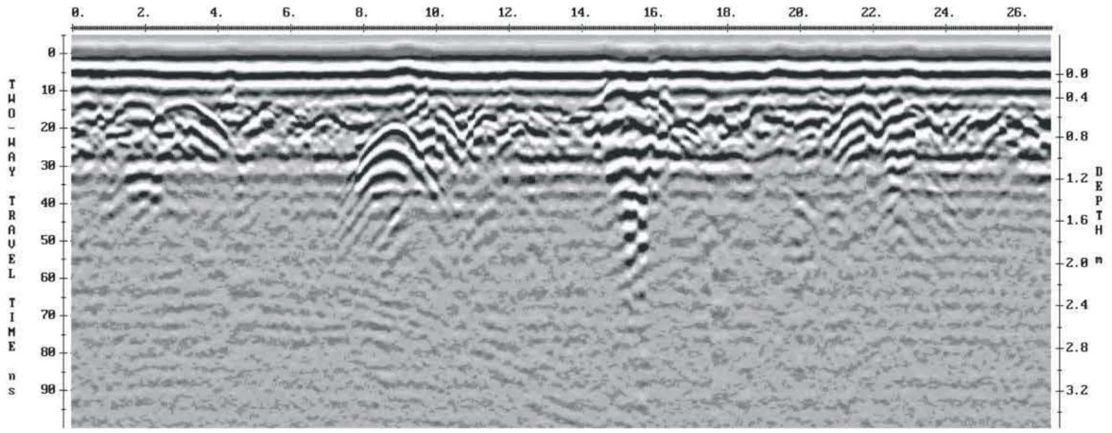

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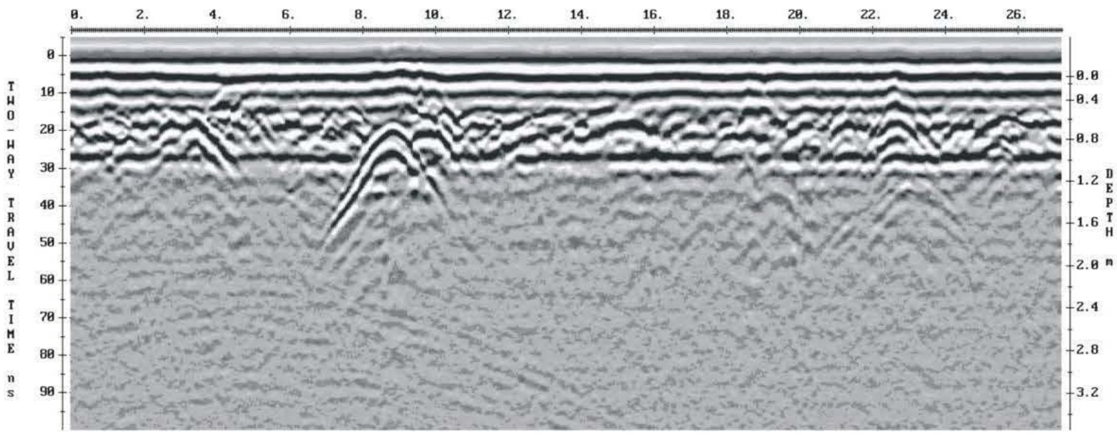

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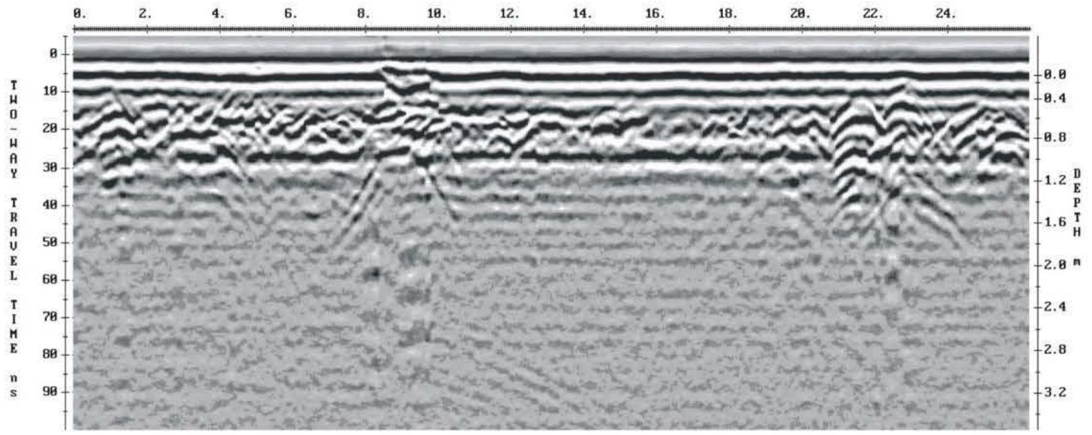

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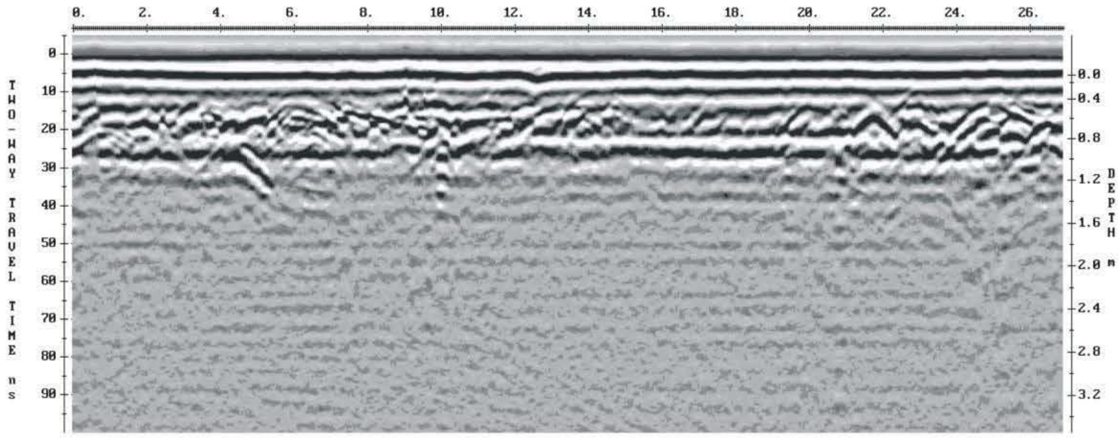

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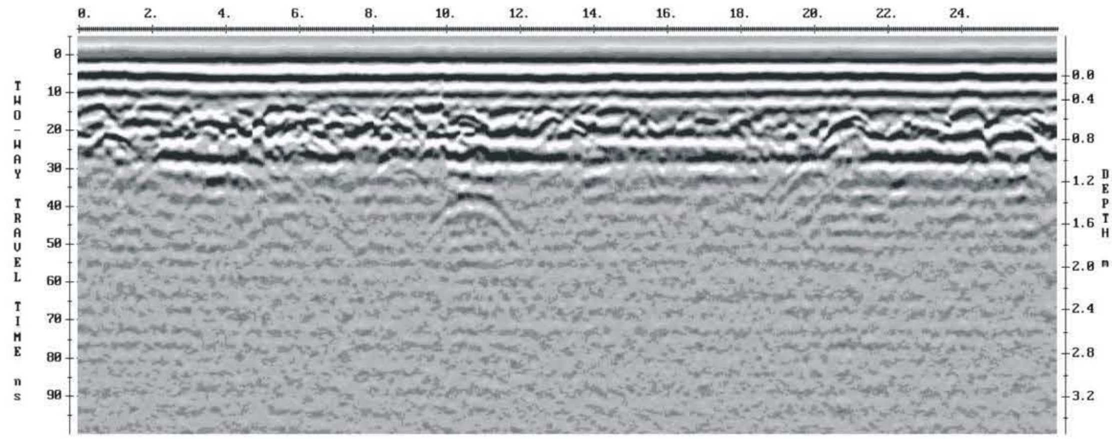

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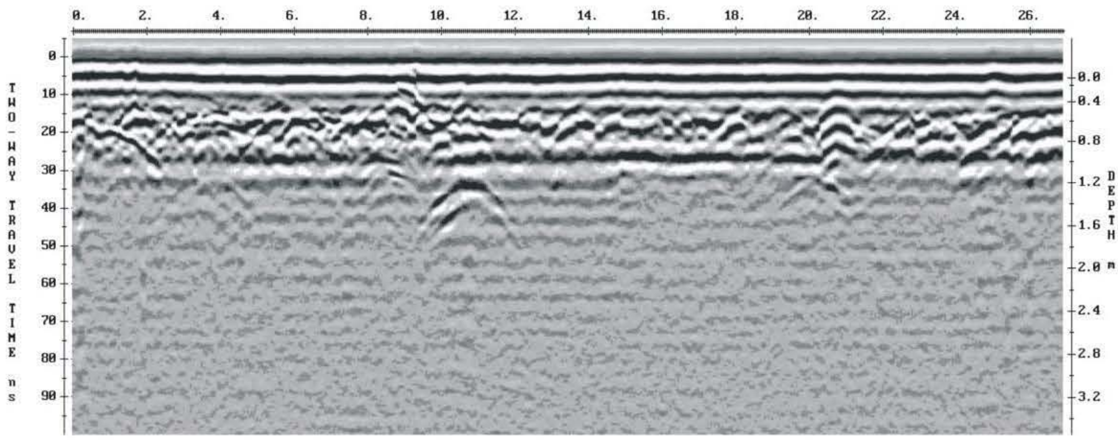

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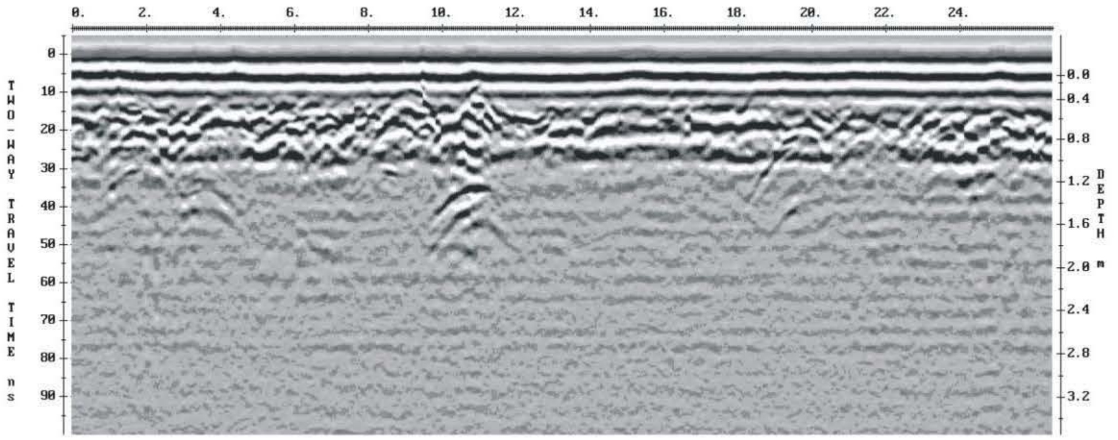

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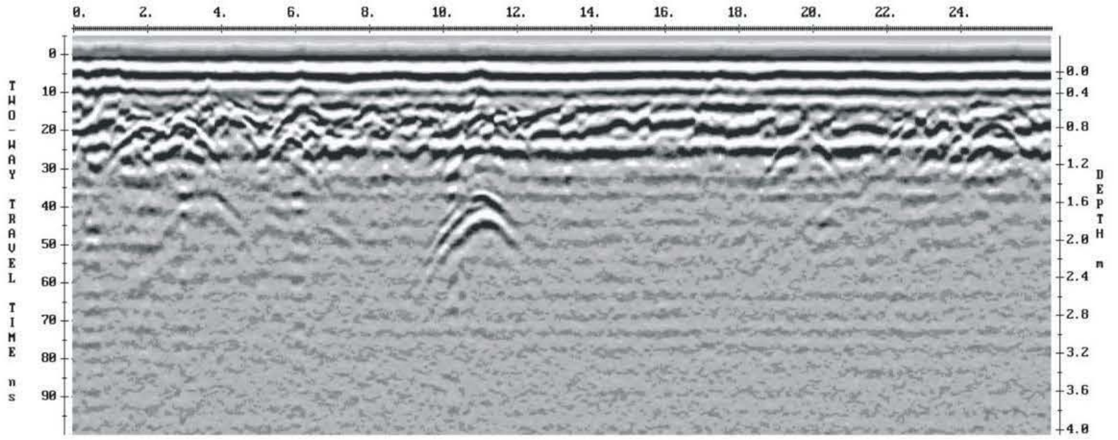

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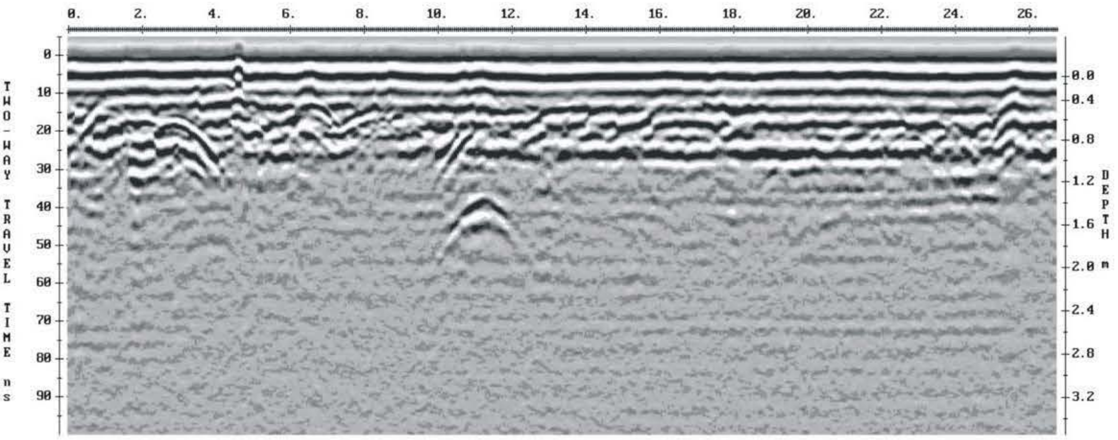

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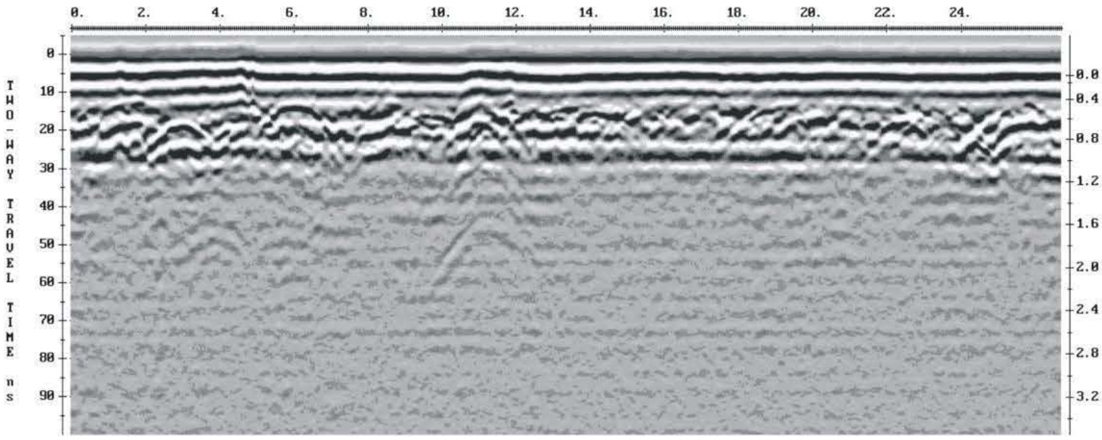

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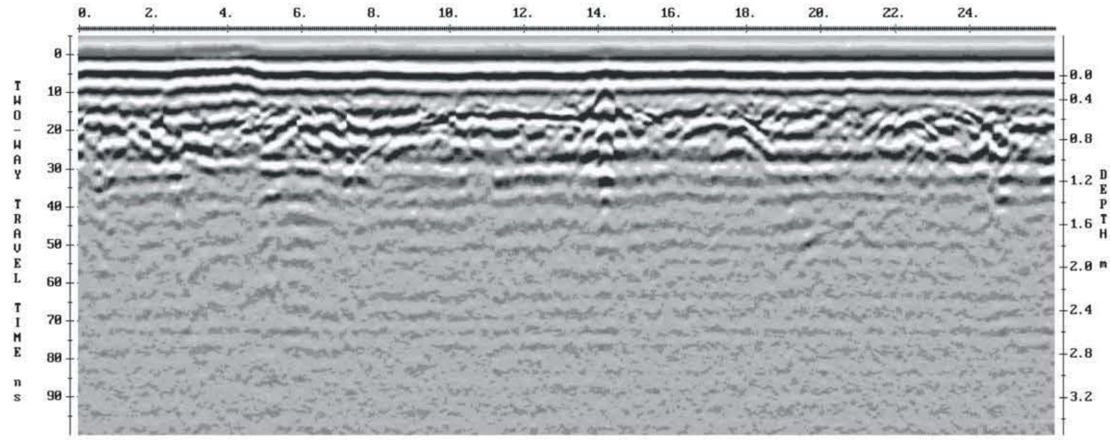

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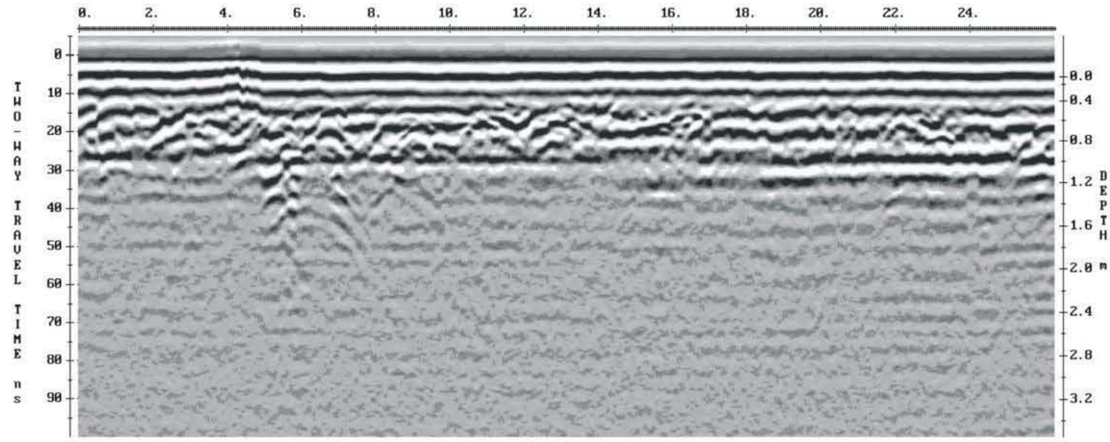

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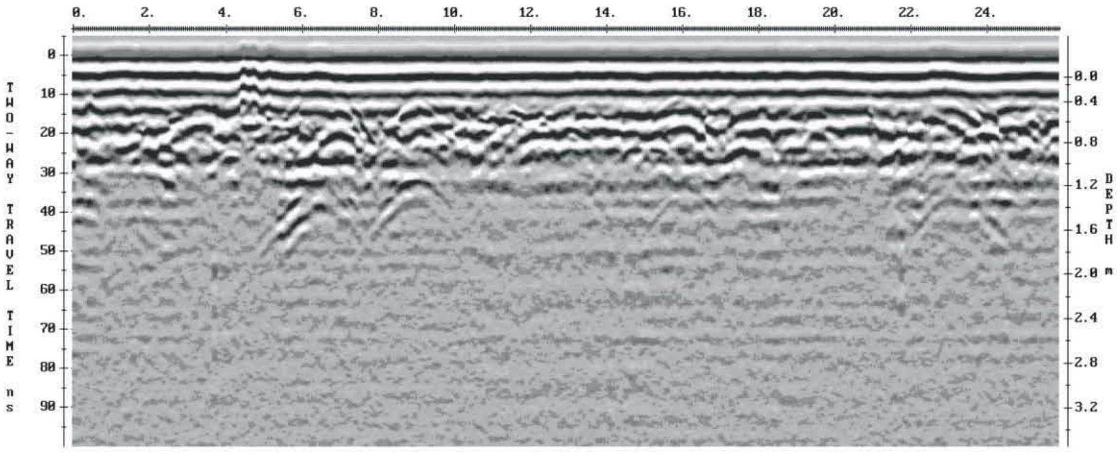

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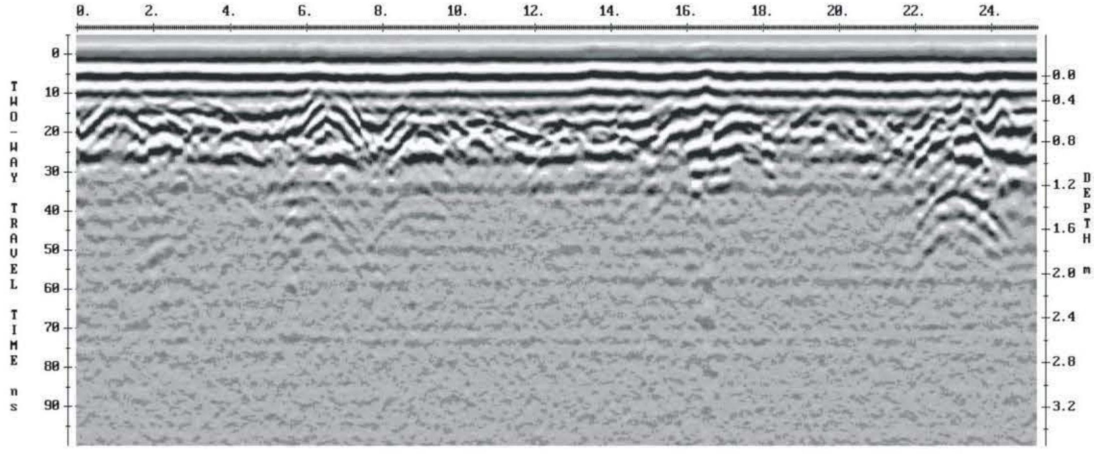

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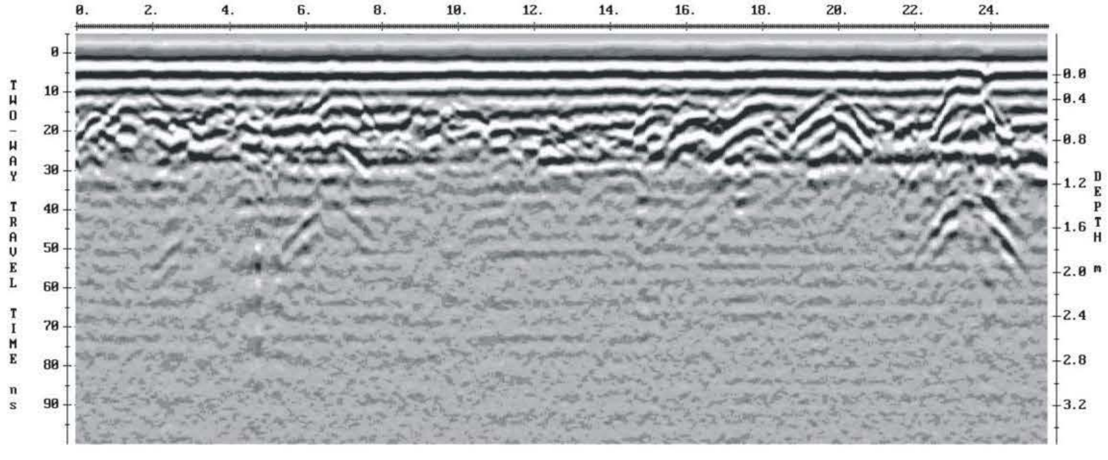

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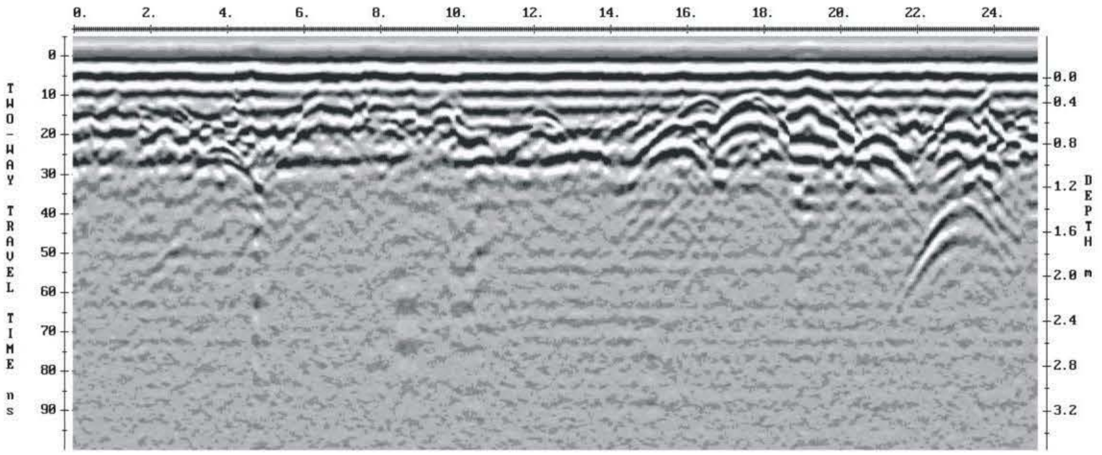

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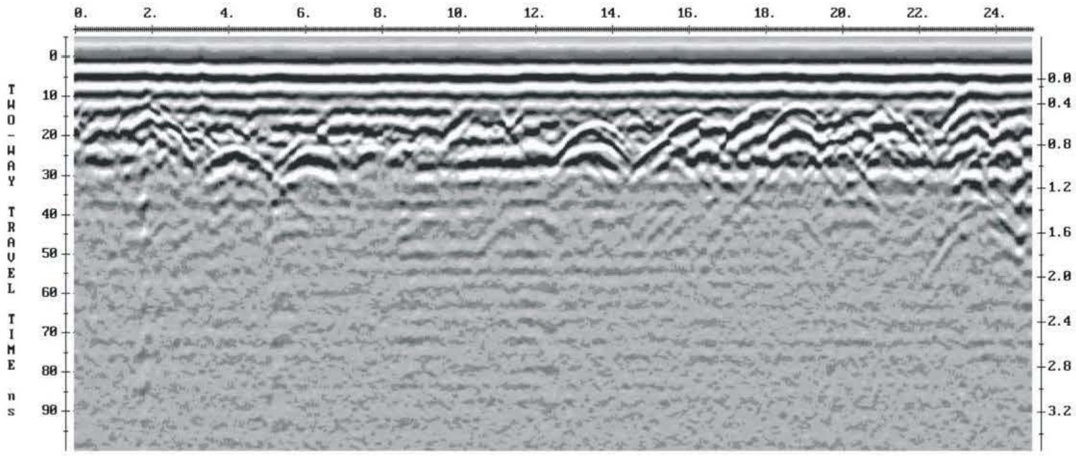

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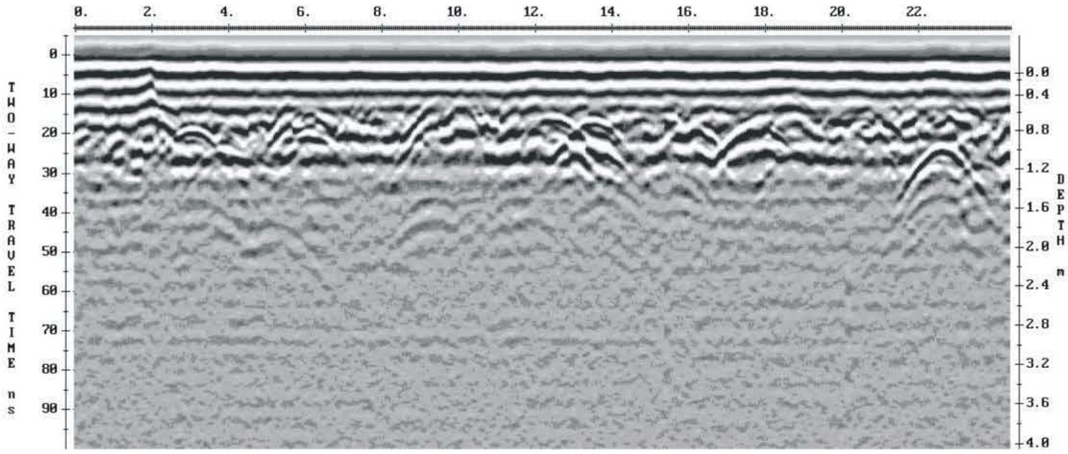

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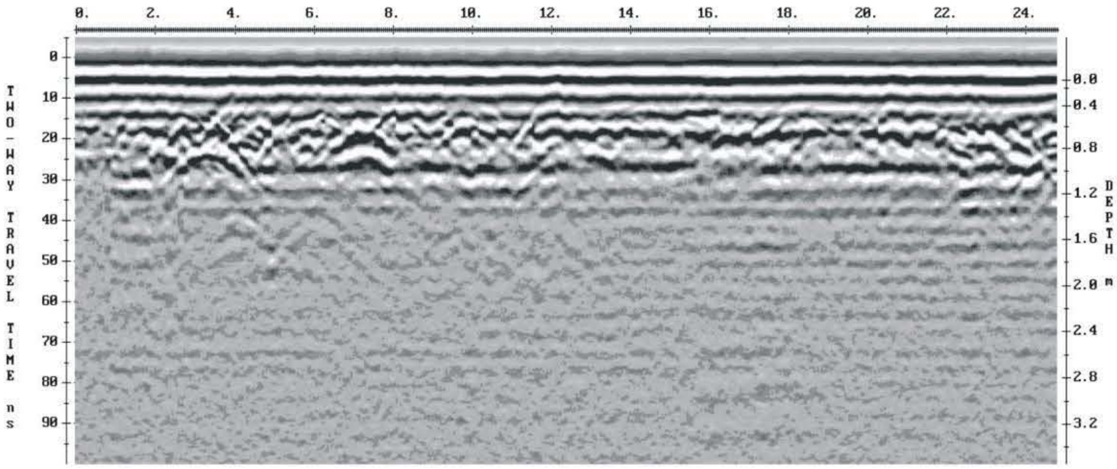

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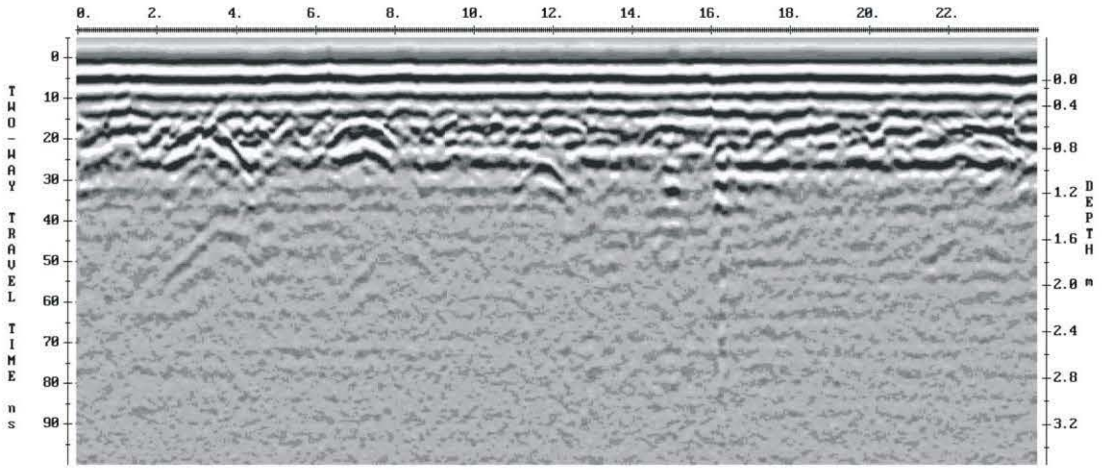

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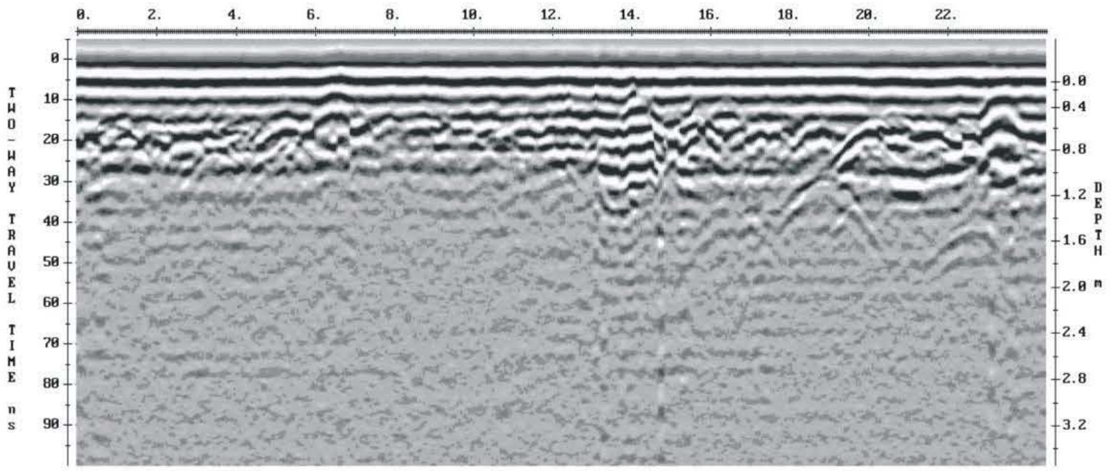

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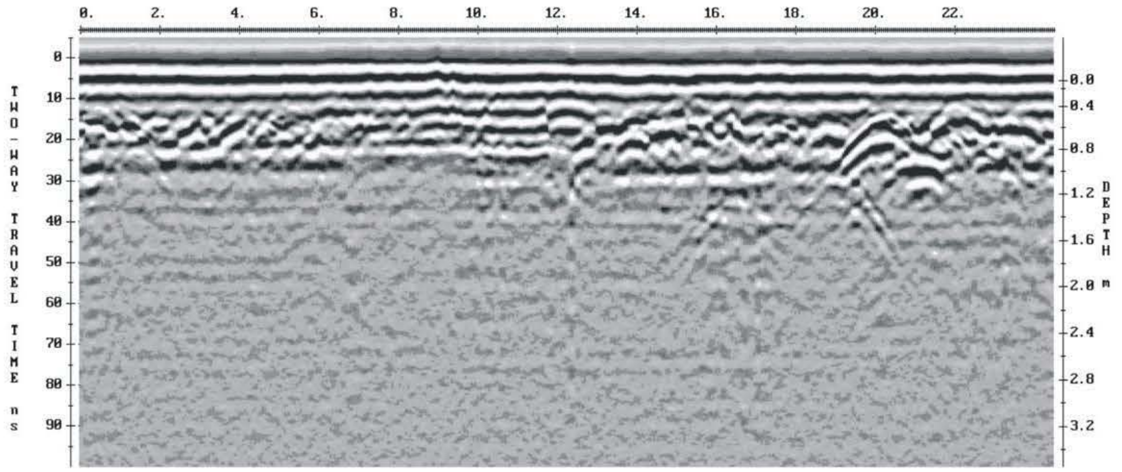

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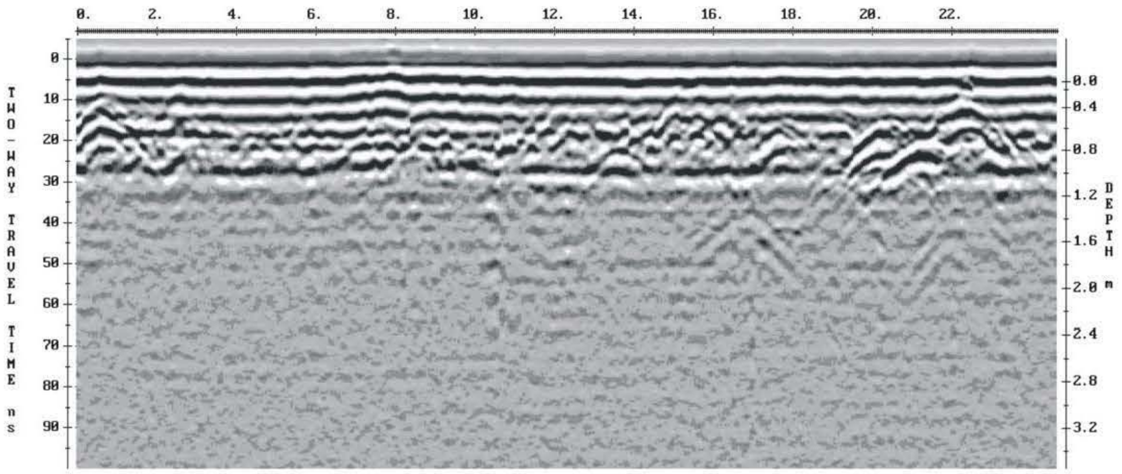

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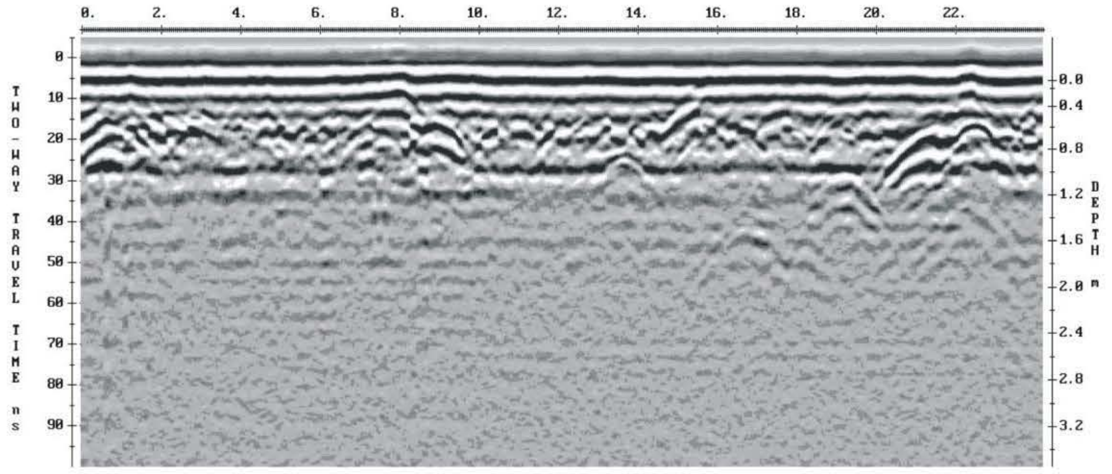

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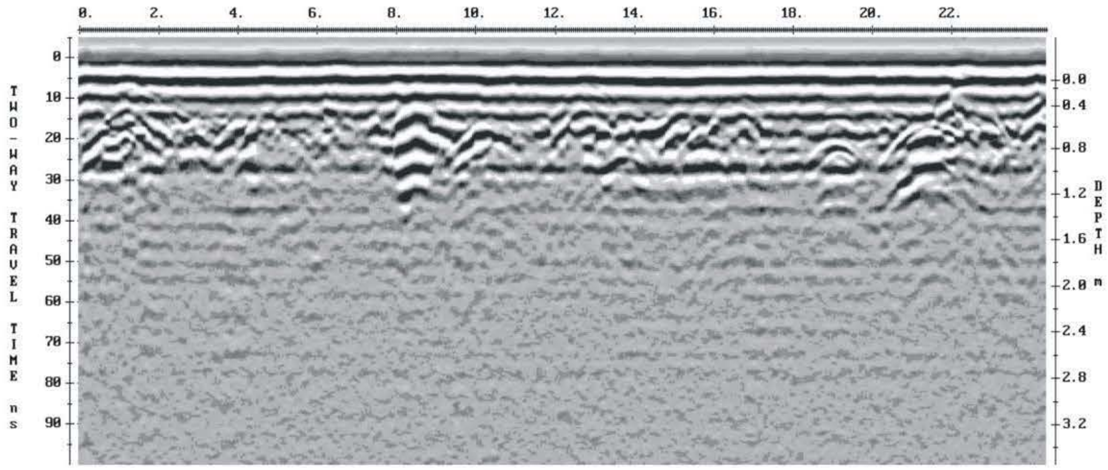

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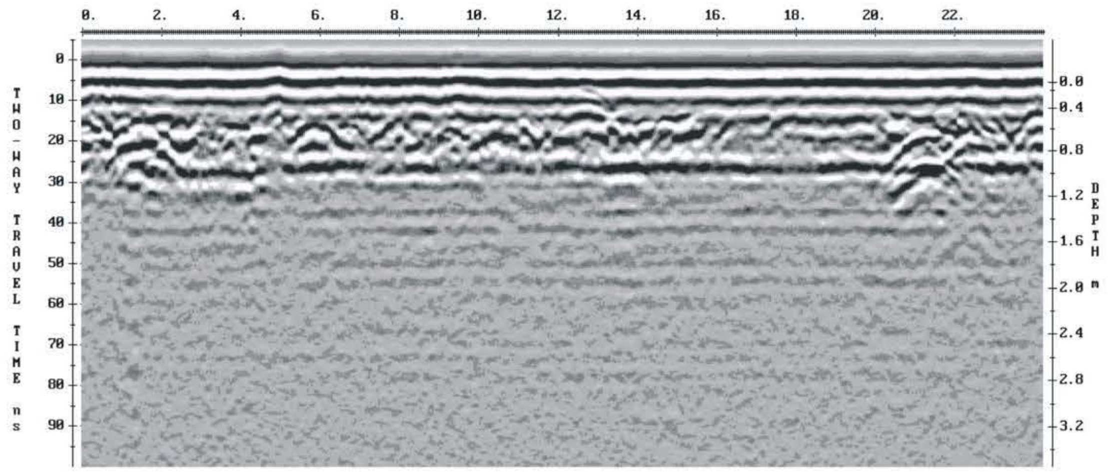

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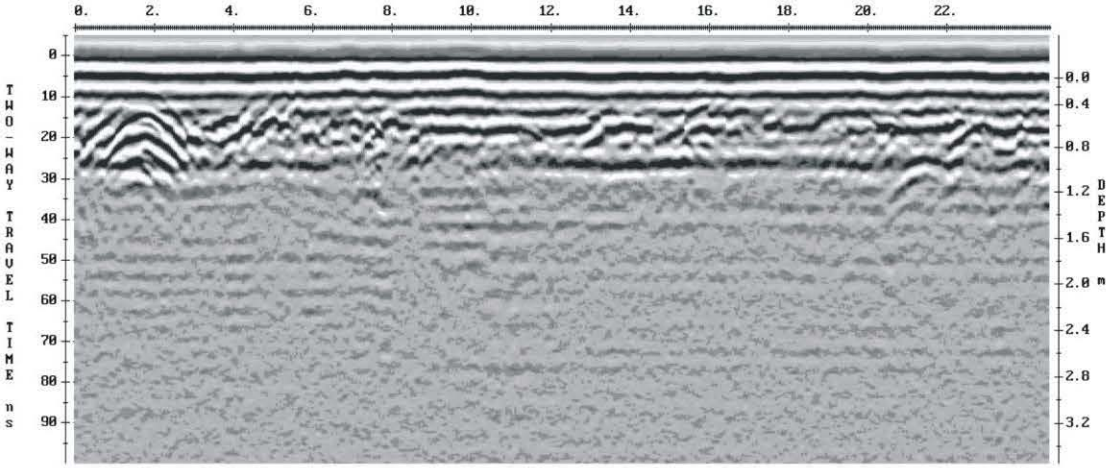

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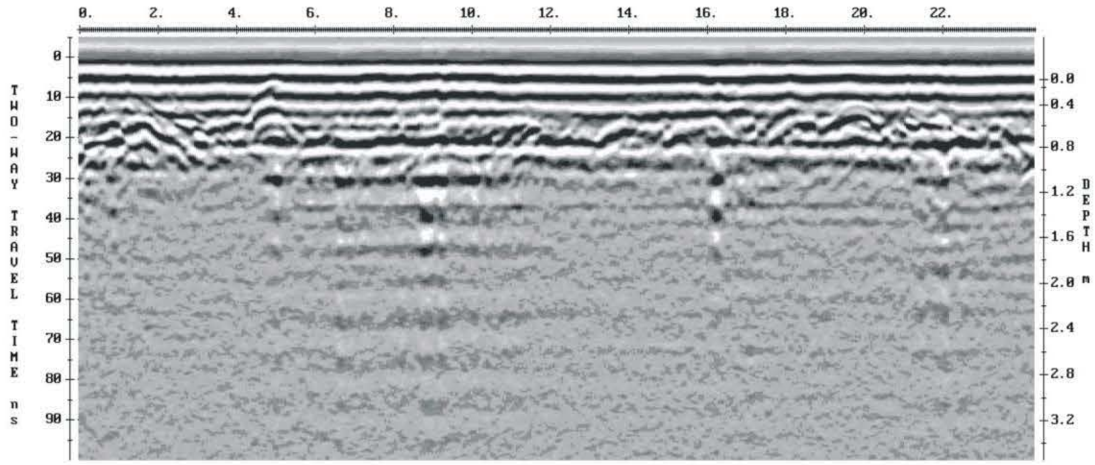

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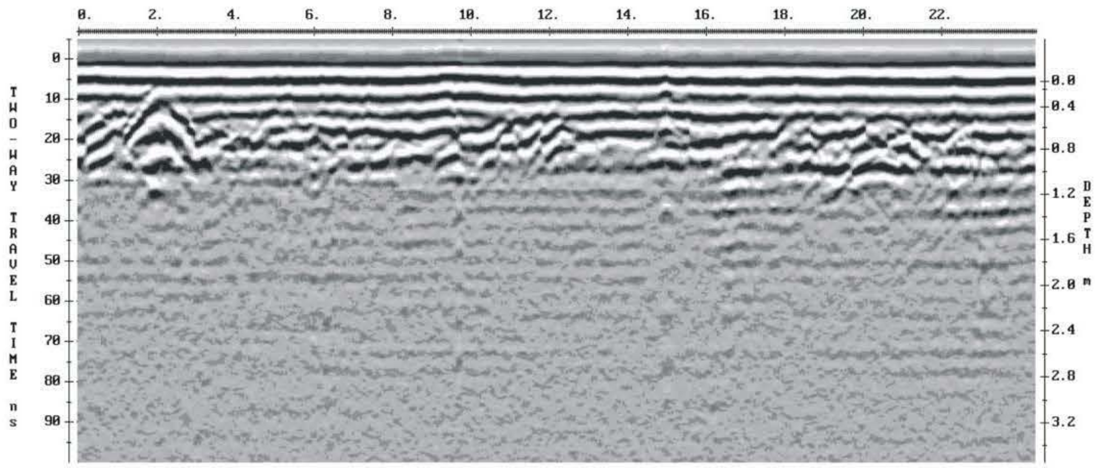

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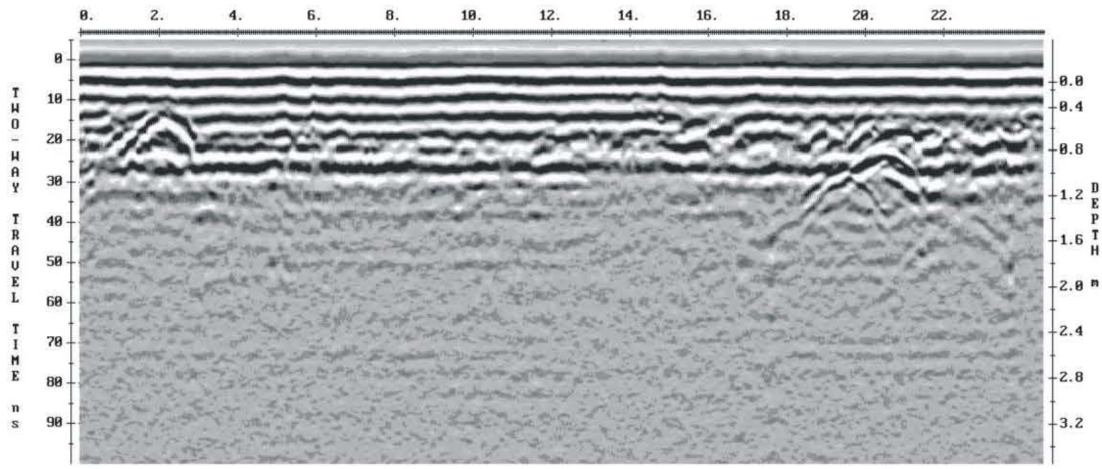

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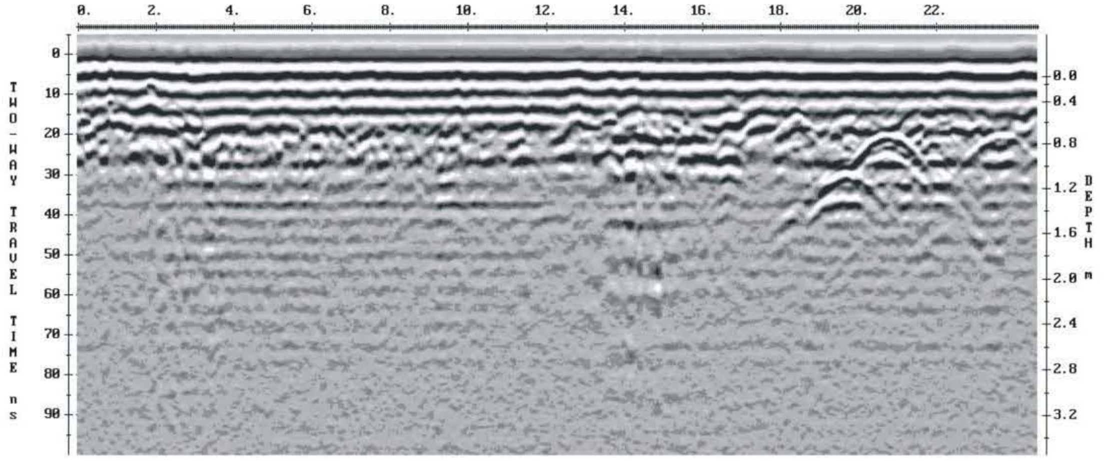

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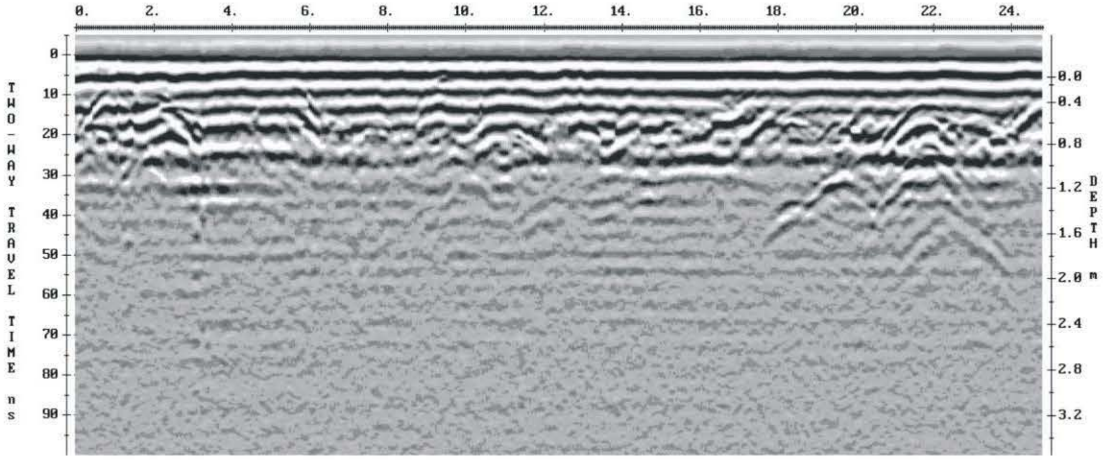

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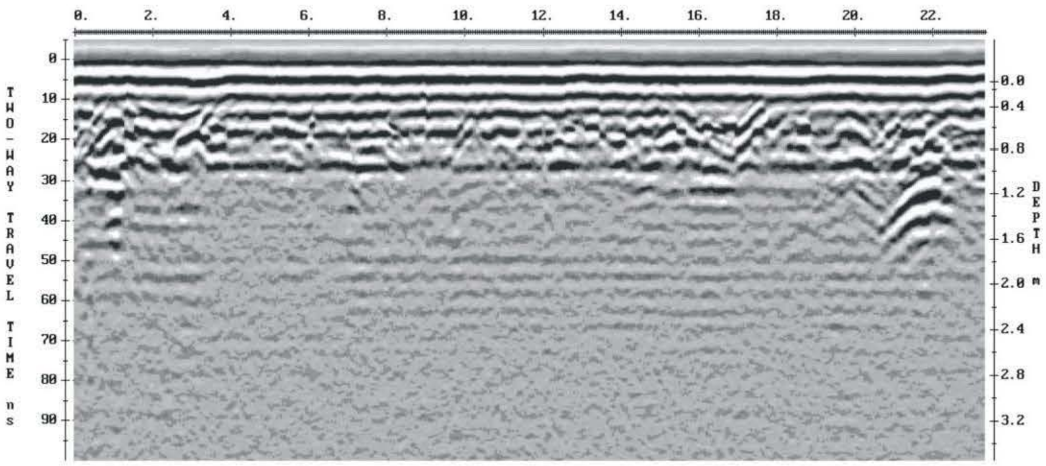

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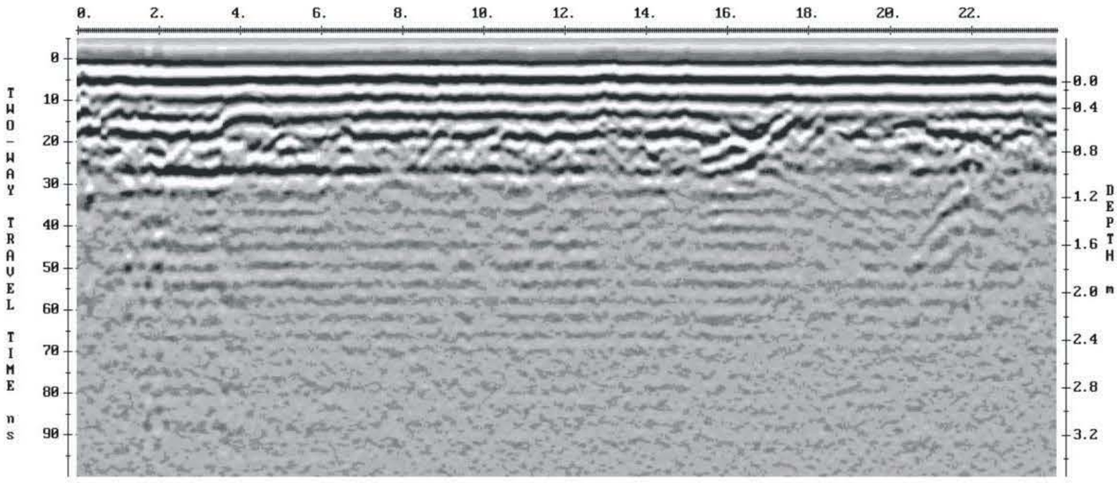
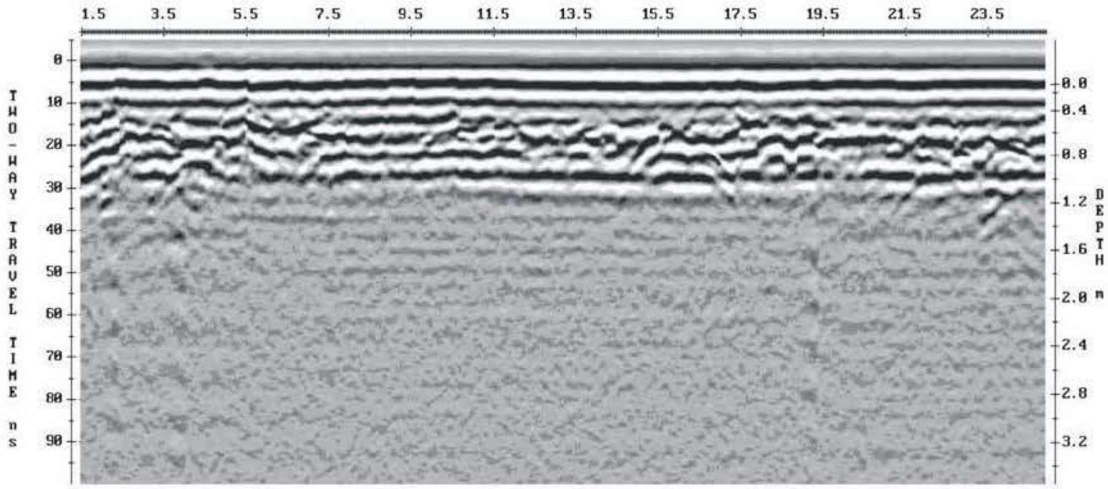

0. 2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22.
TWO-WAY TRAVEL TIME ns
0 10 20 30 40 50 60 70 80 90
DEPTH m
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2

Line 121

APPENDIX V
GPR SURVEYS
(part 2 of 2)

WAIREWA
Upper survey grid
225 MHz Frequency



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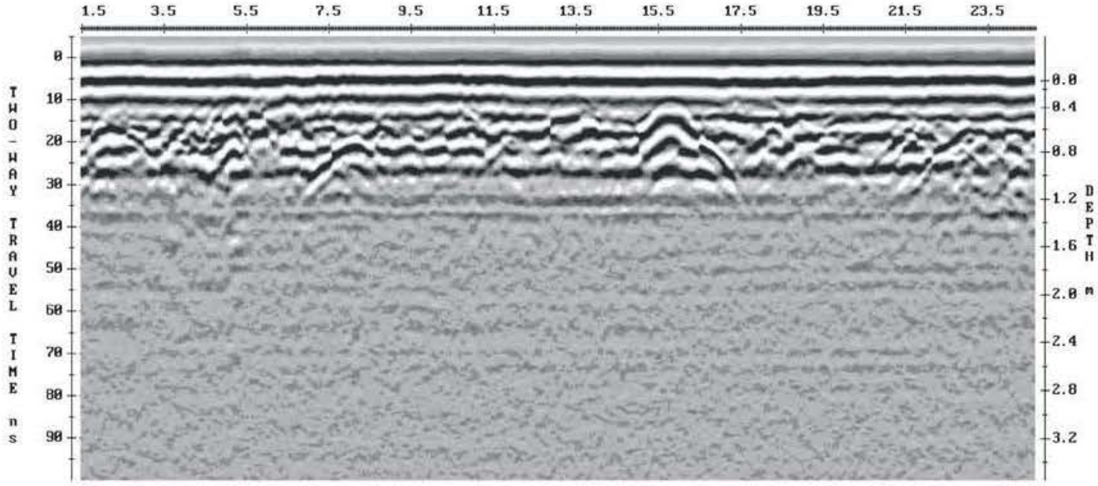

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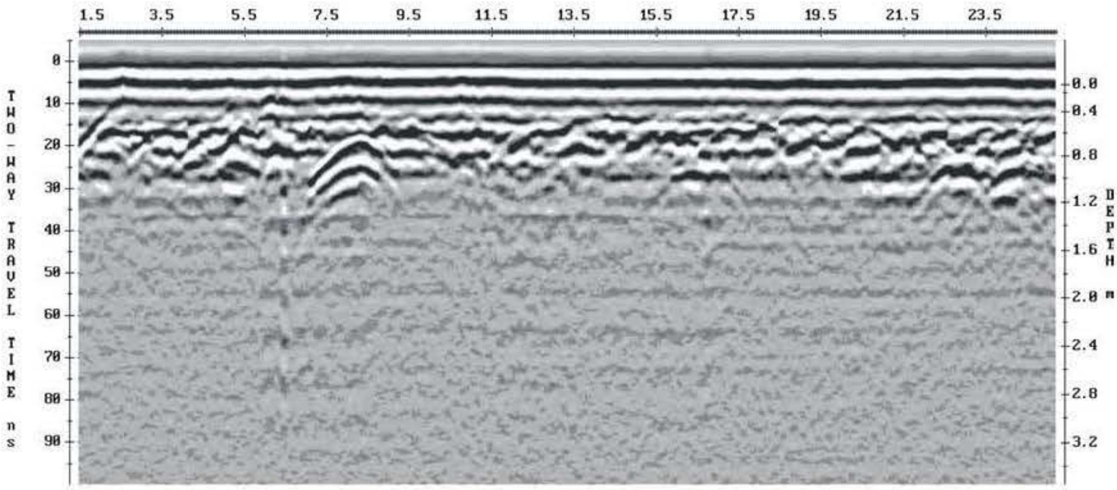

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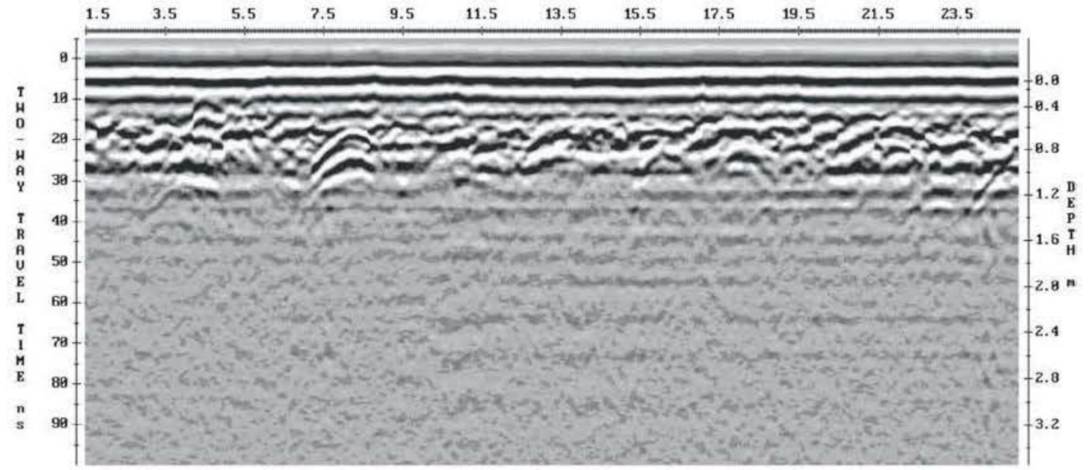

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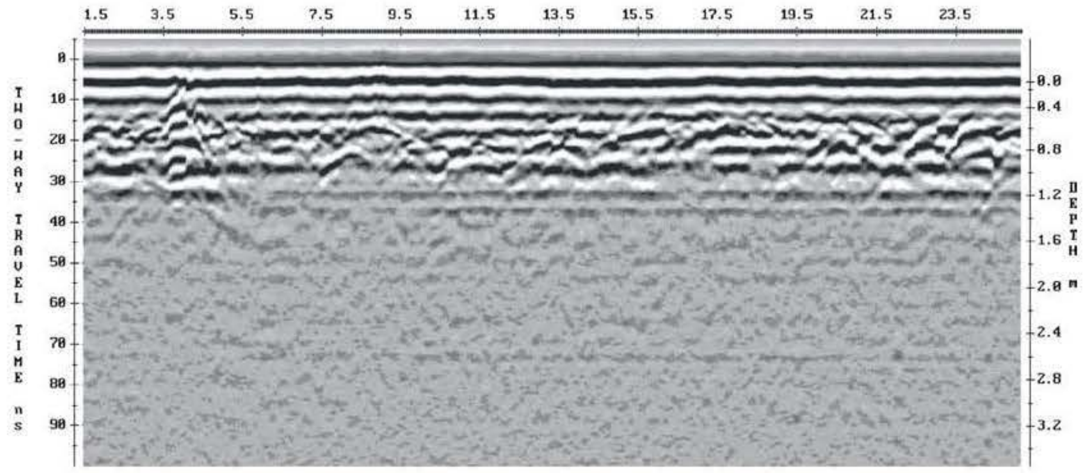

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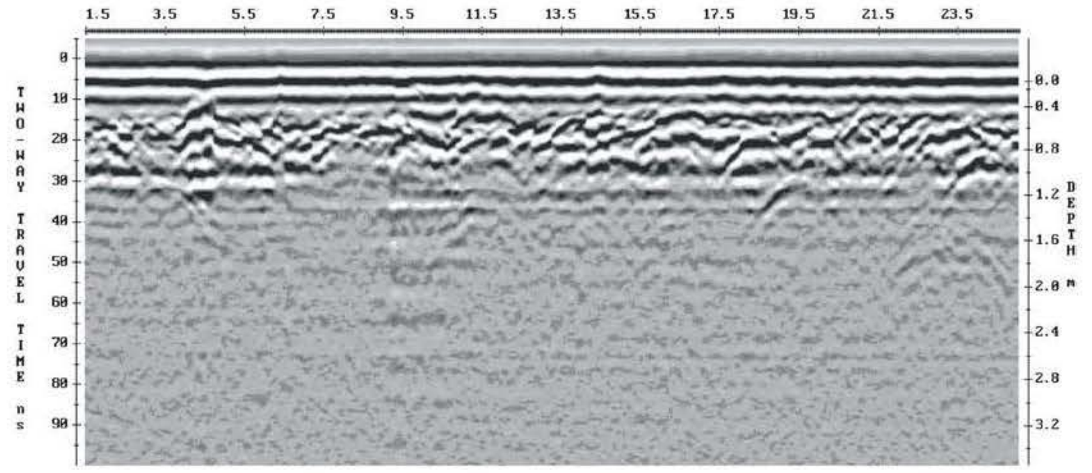

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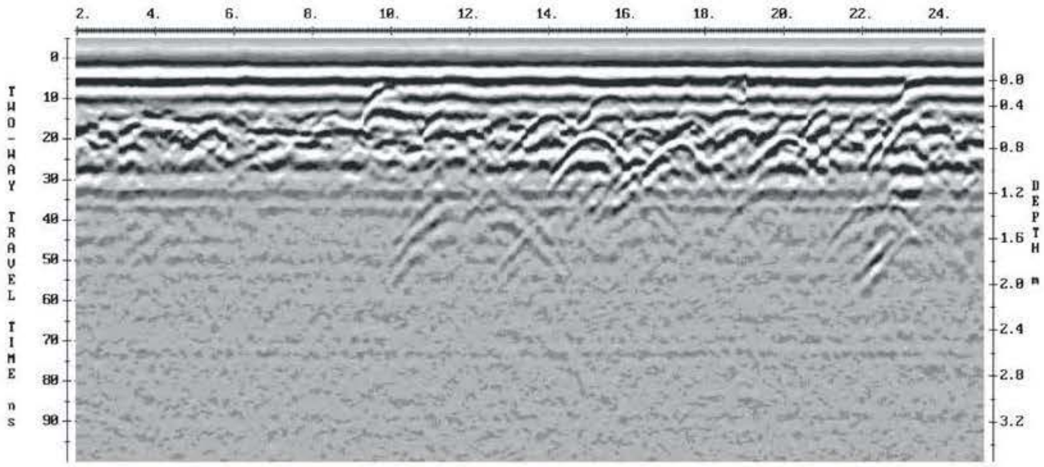

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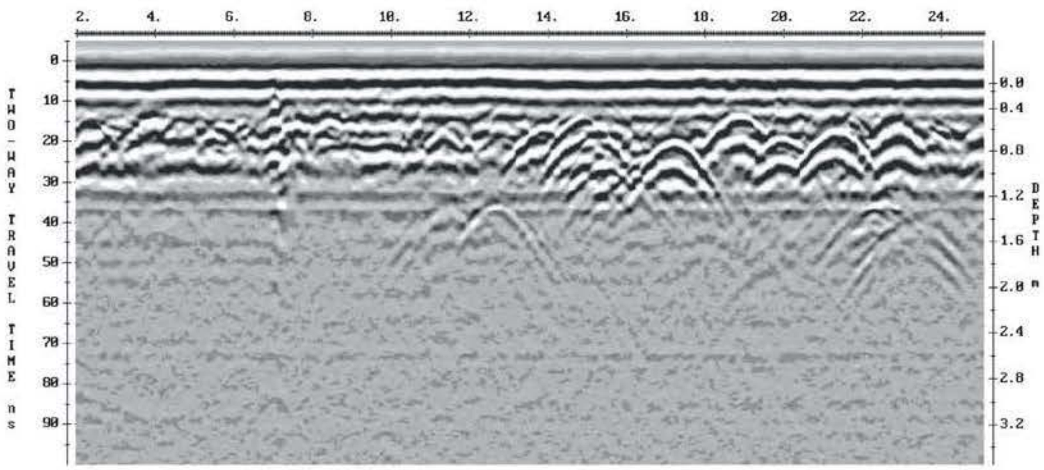

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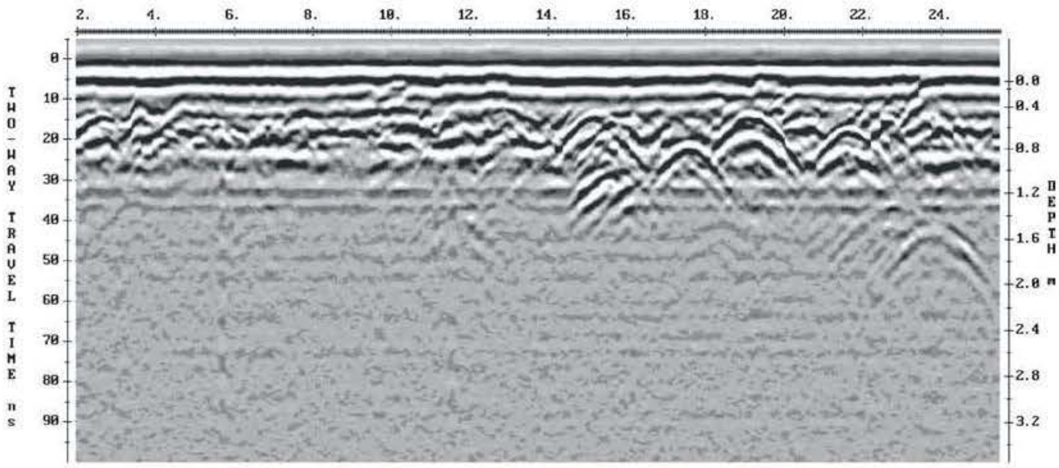

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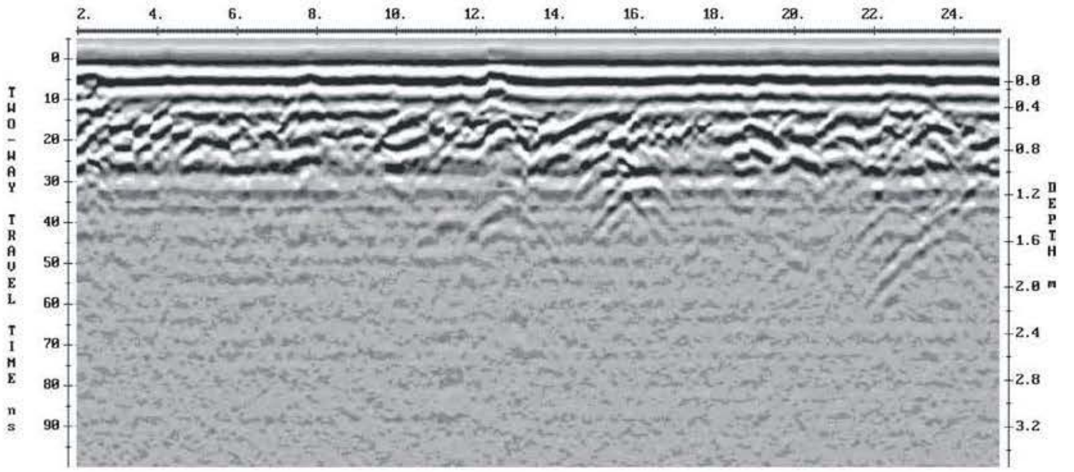

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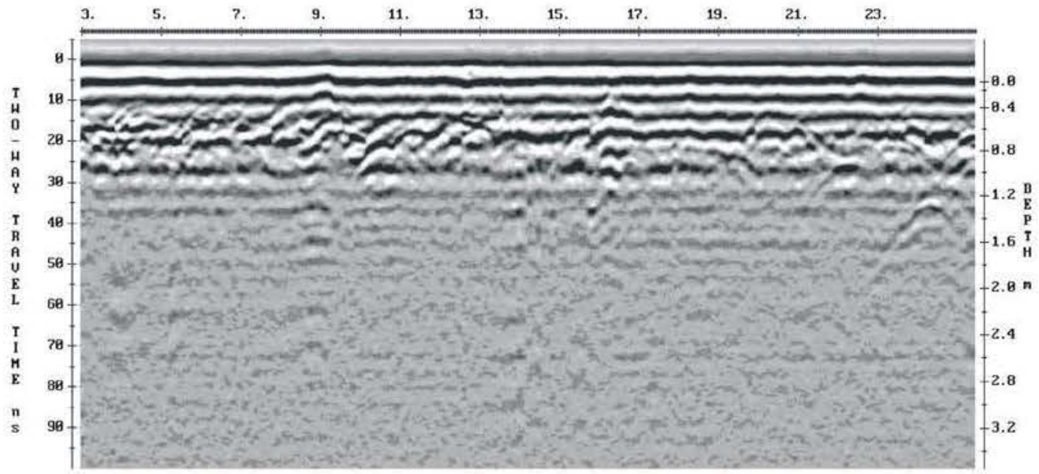

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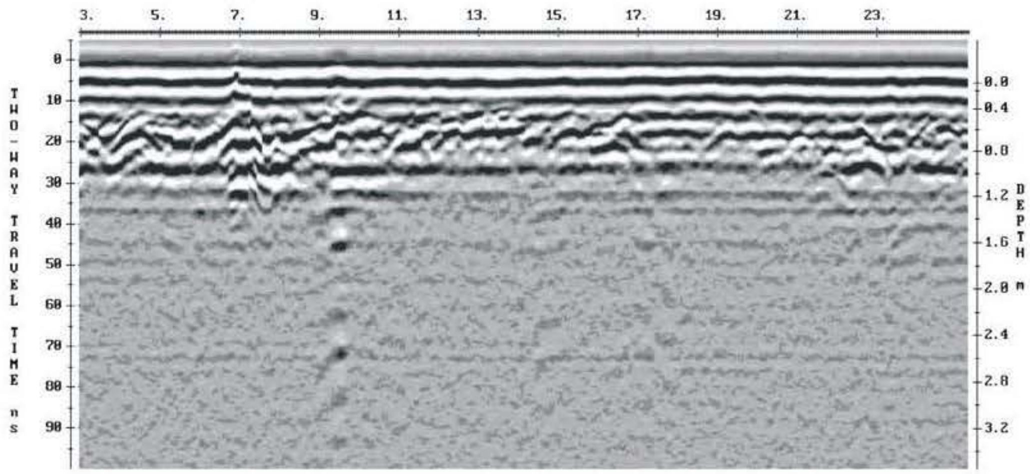

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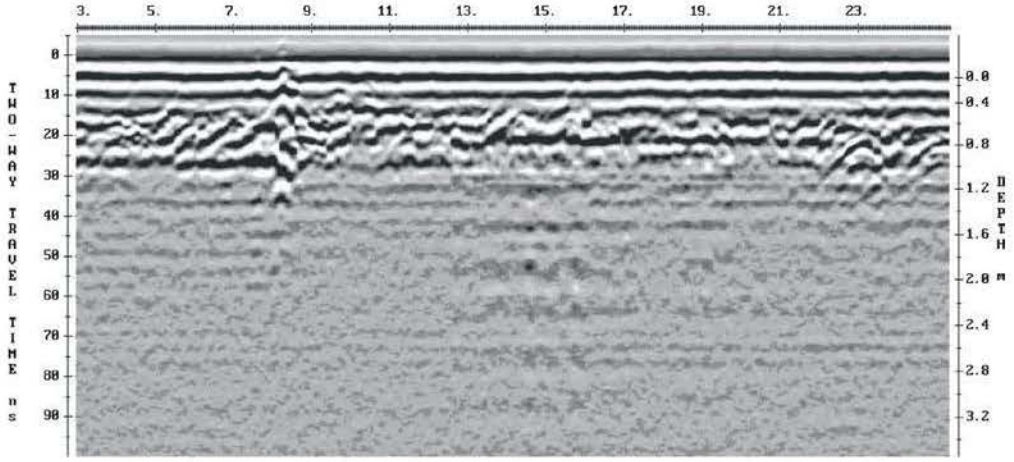

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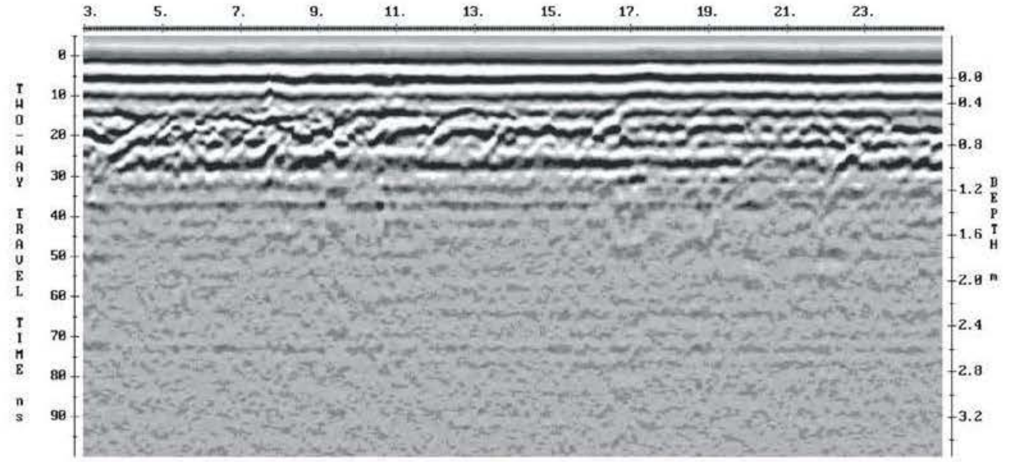

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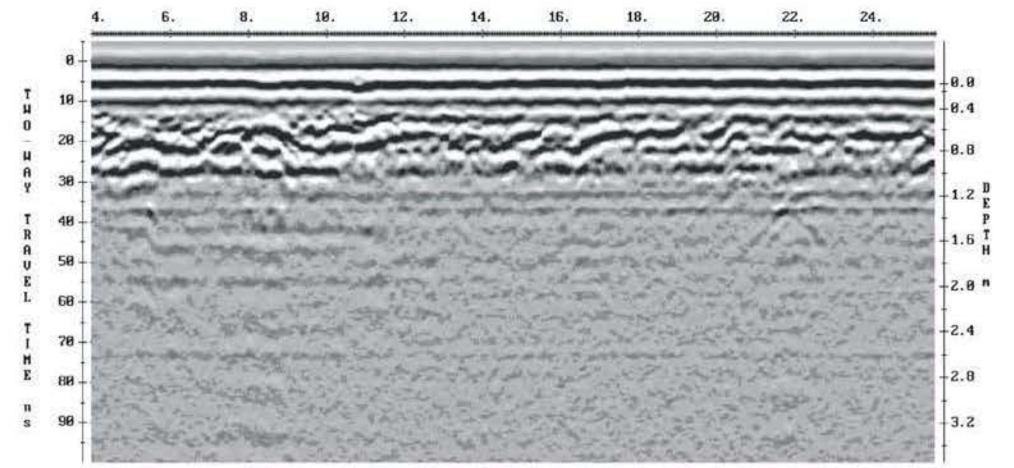

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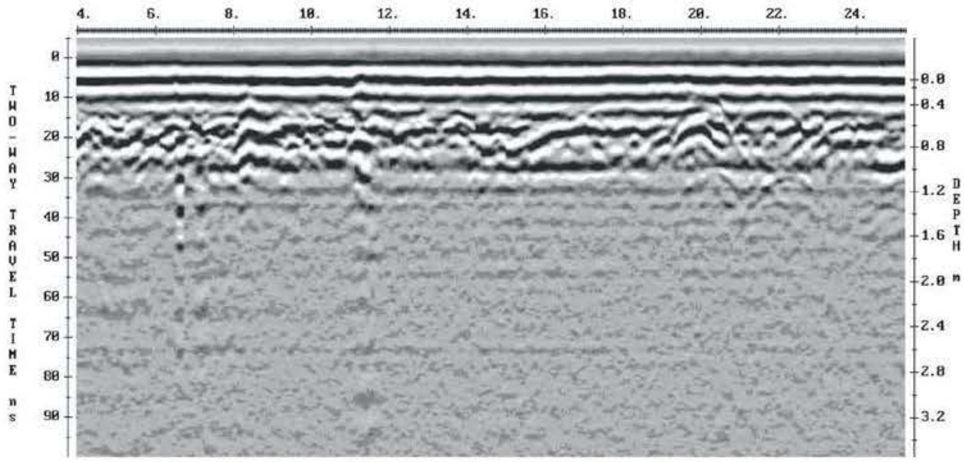

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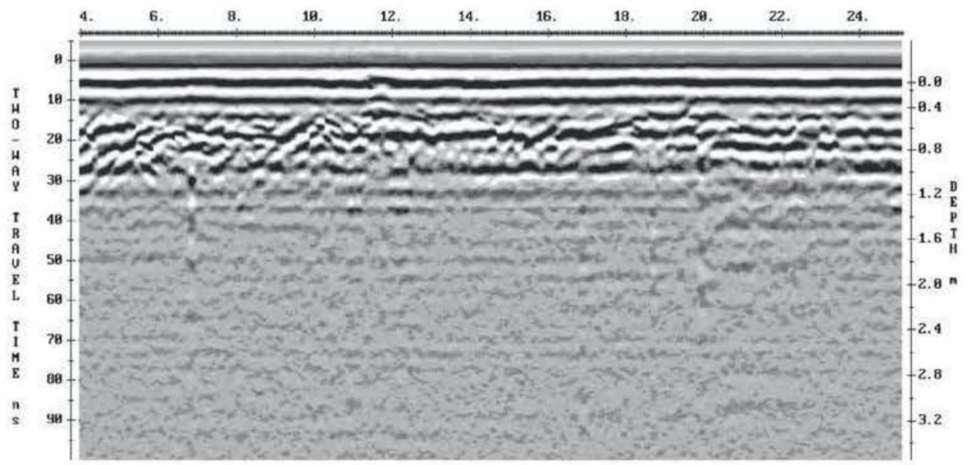

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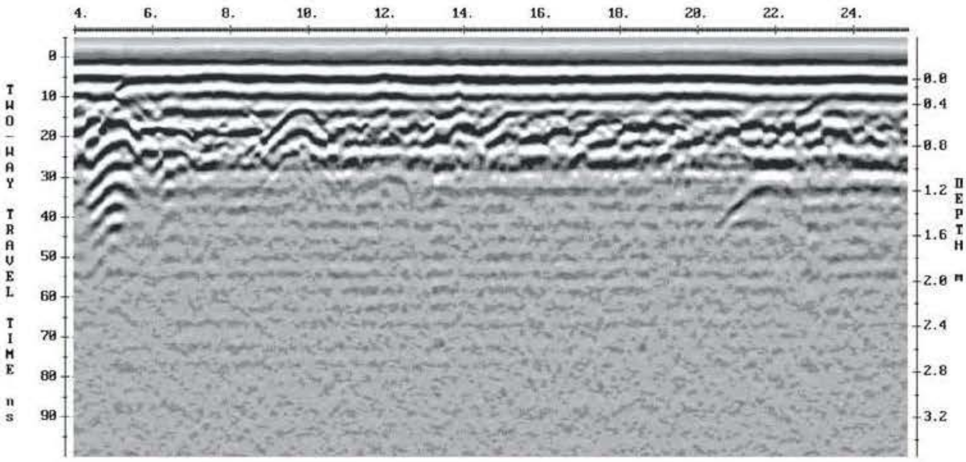

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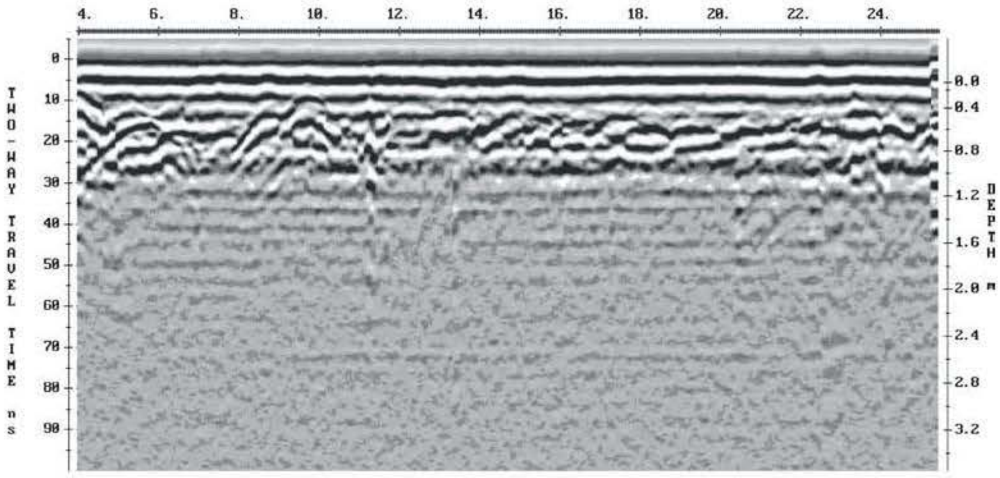

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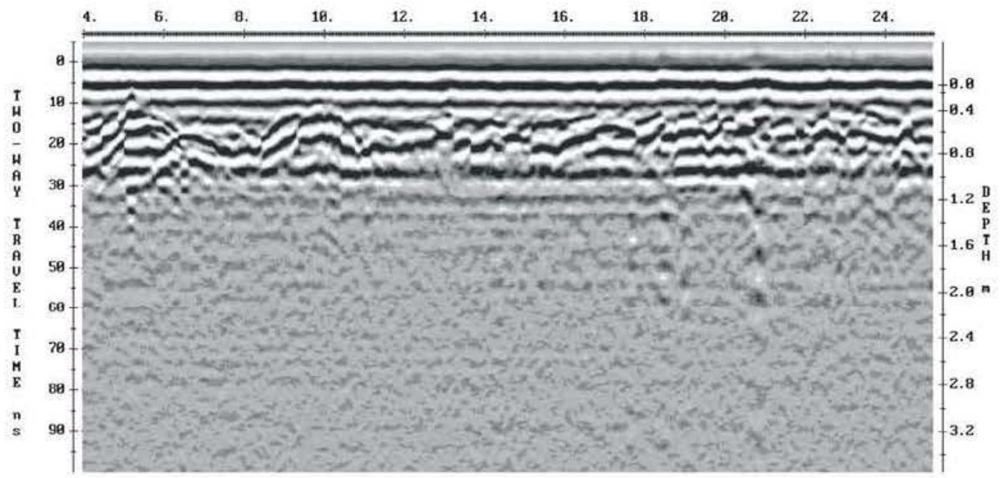

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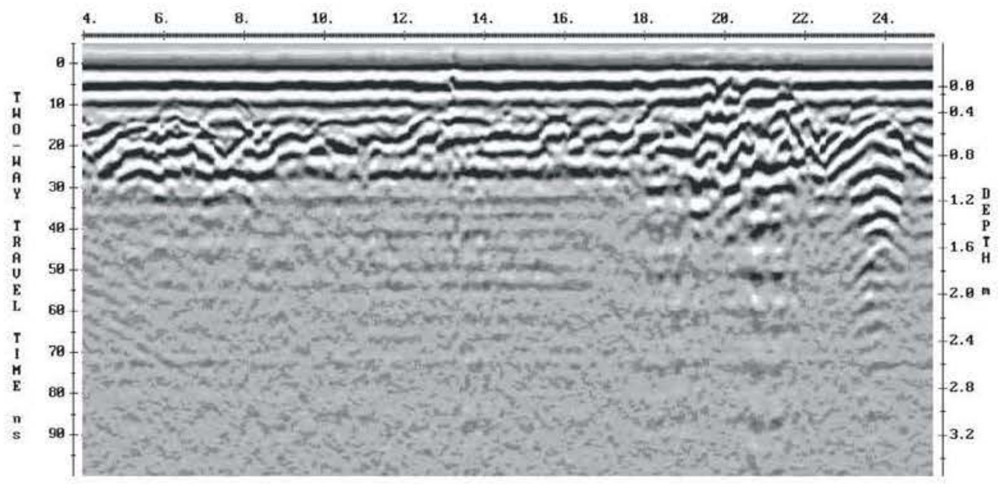

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